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# No. 1. — *A Reconnoissance of the Bahamas and of the Elevated Reefs of Cuba in the Steam Yacht "Wild Duck," January to April,* 1893. By Alexander Agassiz.

The fullest account we have of the structure of the Bahamas is that given by Captain Nelson,[1] who clearly recognized the great part played by the "æolian" rock in the formation of the islands. His examination has formed the basis of the *résumés* of their structure subsequently published by Darwin and by Dana.

Most accurate surveys of the Bahamas have been made by Captains Owen and Barnet, and published by the Admiralty. These charts have immensely facilitated the examination of the banks, and with such excellent guides a great deal of time could naturally be devoted to an examination of the rocks, which otherwise might have to be spent in making surveys of the ground covered. The hydrography of the deep sea has been developed by the "Blake," "Albatross," and other vessels, so that with the aid of the many deep-sea soundings taken in the region of the Bahamas and in the Caribbean many problems can now be discussed for which no data existed as long as the soundings were limited by the 100 fathom line. In a letter to Professor James D. Dana,[2] written at the time, was given a short account of my explorations. This is reproduced here, as the most convenient method of showing the track of the "Wild Duck" among the Bahamas and along the Cuban coast.

Passing out of Nassau, we entered the Bahama Bank at Douglas Channel and crossed the bank to Northern Eleuthera, where we examined the "Glass Window" and the northern extremity of Eleuthera. We then sailed along the west shore of the island close enough to get a good view of its characteristic features as far as Rock Harbor at the southern end. We steamed out into Exuma Sound through Powell Point Channel, and round the southern end of Eleuthera past Little San Salvador and to the northwest end of Cat Island, where are the highest hills of the Bahamas. We then skirted Cat Island along its western face, rounded the southern extremity, and made for Riding Rocks on the western side of Watling Island. We circumnavigated Watling, passed over to Rum Cay, then to the northern part of Long Island, visiting Clarence Harbor; we next crossed to Fortune Island, rounded the southern extremity, and passed to the east side, near the northern end of the island, on the Crooked Island Bank. Leaving the bank by the same track, we skirted its southern face, and steamed to Caicos Bank, crossing that bank from French Cay to Long Island, passed by Cockburn Harbor, and ended our eastern route at Turk's Island. From Turk's Island we made Cape Maysi, skirting the southern shore of Cuba as far as Santiago de Cuba.

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[1] On the Geology of the Bahamas, and on Coral Formations generally, by Captain R. J. Nelson, R. E. Quart. Jour. Geol. Soc. of London, Vol. IX. p. 200, 1853.

[2] Observations in the West Indies. By Alexander Agassiz. (In a letter to J. D. Dana, dated Steam Yacht "Wild Duck," Nassau, March, 1893.) American Journal of Science, Vol. XLV. p. 359, April, 1893.

After coaling there we visited Inagua, and next steamed to Hogsty Reef, a regular horseshoe-shaped atoll with two small cays at the western entrance, where we passed three days studying the atoll. This to me was an entirely novel experience; we were at anchor in three fathoms of water, surrounded by a wall of heavy breakers pounding upon the narrow annular reef which sheltered us, forty-five miles from any land, with a depth of nine hundred fathoms only three miles outside our quiet harbor. I made some soundings in the lagoon and of the slope of the reef outside. From Hogsty Reef we returned to Crooked Island Bank, to the westward of which I also made some soundings to determine its slope. Next we again visited Long Island, taking in the southern and northern ends, which I had not before examined. From there we passed to Great Exuma, stopping at Exuma Harbor and sounding into deep water on our way out. We skirted the line of cays fringing Exuma Sound to Conch Cut, where we entered the bank and sailed west, crossing to Green Cay. From there we made the southwest end of New Providence, and returned to Nassau.

On our first cruise we were fortunate enough to strike Cape Maysi a short time after daylight, and thus had a capital chance to observe the magnificent elevated terraces and raised coral reef which skirt the whole of the southern shore of Cuba from Cape Maysi to Cape Cruz, and make so prominent a part of the landscape as seen from the sea. We were never more than three miles from shore, and had ample opportunity to trace the course of some of the terraces as far as Santiago, and to note the great changes in the aspect of the shores as we passed westward, due to the greater denudation and erosion of the limestone hills and terraces to the west of Cape Maysi, which seems to be the only point where five terraces are distinctly to be seen. The height of the hills back of

Point Caleta, where the terraces are most clearly defined, I should estimate at nine hundred to one thousand feet; though the hills behind the terraces, which, judging from their faces, are also limestone, reach a somewhat greater height, perhaps eleven to twelve hundred feet.

During our second cruise we steamed from Nassau for Harvey Cay, crossing the bank from north to south as far as Flamingo Cay, and from there passing to the westward of Seal Cay, Nurse Cay, etc. to Great Ragged Island, from which we took our departure for Baracoa.

At Baracoa I hoped to be able to ascend the Yunque; unfortunately, the trip was given up, owing to the desperate condition of the roads. From Baracoa we steamed to the westward close to the shore, touching at Banes, Padre, Cay Confites, Sagua, Cay Frances, Cardenas, Matanzas, and finally ending at Havana. On this trip we continued the observations made on the south coast of Cuba, and thus traced the gradual disappearance of the terraces from Baracoa to Nuevitas, and their reappearance from Matanzas to Havana, from the same causes which evidently influenced their state of preservation from Cape Maysi west. We obtained a pretty clear idea of the mode of formation of the flask-shaped harbors found not only on the northern coast of Cuba to the eastward of Nuevitas, but all along the southern coast, and between Matanzas and the Colorado Reefs. They give us in part the explanation of the mode of formation of the extensive system of cays reaching from Nuevitas to Cardenas, and which find their parallel on the south coast of Cuba from Cape Cruz to Cape Corrientes, only upon a much wider plateau, and in the chain of cays stretching towards the western extremity of Cuba behind the Colorado Reefs.

From Havana we steamed to Cay Sal Bank, visited Cay Sal, the Double Headed Shot Cays, and the Anguila Islands, and then crossed the nearest point of the Great Bahama Bank. The bottom of this bank is of a most uniform level, three and three and a half fathoms for miles, sloping very gradually towards the west shore of Andros, so that we anchored nearly six miles from Wide Opening of the central part of Andros which we visited. The bottom consists of a white marl, resembling when brought up in the dredge newly mixed plaster of Paris, and having about its consistency just as it begins to set. The same bottom extends to the shore, and the land itself, which is low where we landed (Wide Opening), not more than ten to fifteen inches above high-water mark, is made up of the same material, and feels under foot as if one were treading upon a sheet of soft India-rubber. Of course on shore the marl is drier, and has the consistency of very thick dough. It appears to be made up of the same material as the æolian rock of the rest of the Bahamas, but from want of drainage it has become thoroughly saturated with salt water. In that condition it crumbles readily, and is then triturated into a fine impalpable powder, almost like deep-sea ooze, which covers the bottom of the immense bank to the west of Andros. After leaving Andros we crossed the bank to Orange Cay, following the eastern edge of the Gulf Stream to the Riding Rocks, Gun Cay, and the Beminis. We then passed to Great Isaac, where we saw some huge masses of æolian rock which had been thrown up along the slope of the cay about eighty feet from high-water mark to a height of twenty feet. One of these masses was fifteen feet six inches long by eleven feet by six feet. We then kept on to Great Stirrup Cay, and, coasting along the Berry Cays, crossed over to Morgan's Bluff on the east side of Andros, running down as far as Mastic Point, and then returned to Nassau.

We made several attempts to examine the eastern side of Andros, but only succeeded in reaching North Bight, being invariably driven back to Nassau by northers. We made a special expedition to the Little Bahama Bank, running eastward from Nassau south of Rose Island to Fleeming Channel, where we passed into Northeast Providence Channel and anchored near Current Island Cut. We crossed to Great Abaco at the Hole in the Wall, following the southwest shore of that island to Gorda Cay. We entered the bank at Mores Island Channel, steamed to the Woollendean Cays and to Rock Harbor, examining the "Marls" to the westward of Great Abaco. Returning, we passed into Northwest Providence Channel, steamed north to Burrow Cay, and skirted the southern shore of Bahama Island as far as Settlement Point. At Memory Rock we entered the bank, steering east past Great Sale Cay for Pensacola Cay, and from there keeping in the channel between the outlying cays and Great Abaco as far as Green Turtle Cay. Here we passed out from the Bank through Whale Cay Channel, and skirted the eastern side of the Little Bahama Bank back to Hole in the Wall, and crossed to Egg Island. We examined both it and Egg Reef on our way to Nassau.

The islands of the Bahamas from the Little Bahama Bank on the north to Cay Sal on the west, and as far as Turk's Island on the east, are all of æolian origin. They were formed at a time when the banks up to the 10 fathom line must have been one huge irregularly shaped mass of low land, the coral sand beaches of which supplied the material that must have built up the successive ranges of low hills which we still find in New Providence, and which are so characteristic of all the ridges of the islands of the group. After the formation of the islands came an extensive gradual subsidence, which can be estimated at about three hundred feet, and during this subsidence the sea has little by little worn away the æolian hills, leaving only here and there narrow strips of land in the shape of the present islands. Inagua and Little Inagua are still in the original condition in which I imagine such banks as the Crooked Island, Caicos, and the Turk's Islands Banks, and other parts of the Bahamas, to have been; while the process of disintegration going on at the western side of Andros still shows a broad island, which will in time leave only the narrow eastern strip of higher æolian hills on the western edge of the Tongue of the Ocean. Such is also the structure of Salt Cay Bank; it owes its shape to the same conditions as those which have given the Bahamas their present configuration. My reason for assigning a subsidence of three hundred feet is that some of the deep ocean-holes on the bank have been sounded to a depth of thirty-four fathoms, and I take them to be submarine blow-holes or cañons in the æolian limestone of the Bahama hills when they were at a greater elevation than now.[1] Subsidence explains satisfactorily the present configuration of the Bahamas, but teaches us nothing in regard to the substratum upon which the Bahamas were built. Indeed, the present reefs form but an insignificant part of the topography of the islands, and they have taken only a secondary part in filling here and there a bight or a cove with more modern reef rock, thrown up against the shores so as to form coral reef beaches such as we find in the Florida Reef.

We steamed in the "Wild Duck" nearly forty-five hundred miles among the Bahamas, visiting all the more important points, and made an extensive collection of the rocks of the group.

I had on board a Tanner sounding machine, kindly lent me for this trip by Colonel McDonald of the Fish Commission, and some deep-sea thermometers were also supplied by him and by Professor Mendenhall, the Superintendent of the United States Coast Survey. I provided myself with a number of self-closing Tanner deep-sea tow-nets, with a supply of dredges and surface tow-nets, and carried on board a Yale and Towne patent winch for winding the wire rope used in dredging and towing in deep water. The yacht was provided with a steam capstan; by increasing its diameter with lagging we found no difficulty in hauling in our wire rope at the rate of a hundred fathoms in eight minutes. We carried six hundred fathoms of steel wire dredging rope of the same dimensions which I had used on the "Blake," and which has also been adopted on the "Albatross."

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[1] Dr. John L. Northrop, ("Notes on the Geology of the Bahamas," Trans. N. Y. Acad. of Sci., Oct. 13, 1890,) who passed considerable time in New Providence and in Andros, has given an excellent account of the characteristic features of Andros. He considers the evidence he has collected as conclusive of the recent elevation of Andros and of New Providence. During my extended examination of the Bahamas I did not meet anywhere with deposits either of corals or of mollusks, the position of which could not be satisfactorily accounted for as resulting from the action of winds and waves, or hurricanes. On the contrary, the very facts Dr. Northrop brings forth regarding the configuration of the western coast of Andros seem to me to lead to the opposite conclusions from those arrived at by him. All the evidence I have shows that the Bahamas owe their present configuration to subsidence and erosion, and that they are not rising.

Both on going into Havana and on leaving we spent the greater part of a day in towing with the Tanner net. I thought I could not select a better spot for finally settling the vertical distribution of pelagic life than off Havana, which is in deep water — nine hundred fathoms — close to land, on the track of a great oceanic current, the Gulf Stream, noted for the mass of pelagic life it carries along its course. We towed in one hundred, one hundred and fifty, two hundred and fifty, and three hundred fathoms, and on the surface at or near the same locality, and I have found nothing to cause me to change the views expressed in the Preliminary Reports of the "Albatross" expedition of 1891.[1] At no depth did I obtain with the Tanner net any species which were not also at some time found at the surface. Even at one hundred fathoms the amount of animal life was much less than in the belt from the surface to that depth. At one hundred and fifty fathoms there was still less, and at two hundred and fifty fathoms and three hundred fathoms the closed part of the Tanner net contained *nothing*.[2] At each of these depths we towed fully as long as was required to bring the net to the surface again. Thus we insured, before the messenger was sent to close the lower part of the bag of the Tanner net, as long a haul through water as the open part of the net would have to travel till it reached the surface. This gave for comparison of their respective richness the fauna of a horizontal column of water obtained in the closed part of the Tanner net at one hundred, one hundred and fifty, two hundred and fifty, and three hundred fathoms, of the same or of greater length than the fauna of a vertical column from those points to the surface obtained in the sweep of the open part of the Tanner net.

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[1] Alexander Agassiz: General Sketch of the Expedition of the "Albatross," from February to May, 1891. Bull. Mus. Comp. Zoöl., Vol. XXIII. No. 1, 1892.

[2] This is fully in accordance with the observations of the Plankton Expedition, as far as they have been published by Apstein, Ortmann, Giesbrecht, and others, relative to the bathymetrical range of the pelagic fauna. The diminution and final disappearance at sea of pelagic animal and vegetable life below a comparatively narrow limit seems general. That there are local conditions near shore, or in comparatively closed or shallow areas, or in districts adjoining submarine banks near the 500 fathom line, which modify these conclusions, I have already stated. Many of the observations which form the basis of statements proving the indefinite extension in depth of the pelagic fauna and flora, are of little value, owing to the imperfect working of the apparatus in use.

In all our tows with the deep-sea self-closing Tanner net we took the usual precautions of carefully filtering the sea water into which the contents of the closed part of the net were emptied. We also made some slight modifications in the construction of the Tanner net. Iron rods were substituted for the rope guides of the pulleys, and one side was loaded so as to cant the net while it was towed. Off Clifton, New Providence, we made some trials in the Tongue of the Ocean, at a distance of not more than a mile from the edge of the bank, the depth being seven hundred fathoms. We towed at 9.30 A. M. in from one hundred to one hundred and ten fathoms for about twenty minutes: the net closed successfully. Only one Copepod was brought up from that depth, while in the open part of the net we obtained several specimens of Eucope, many bells of Diphyes, numerous Copepods, Alciope, Schizopods, larvæ of Brachiurans, Macrurans, Doliolum, Appendicularia, Gasteropod larvæ, and Collozoum. A fine Rhyzophysa came up attached to the wire after hauling in forty fathoms. At 10.30 we took a second tow at three hundred fathoms; the closed part of the net contained nothing, and a preliminary examination of the contents of the open part of the net, which remained open from three hundred fathoms to the surface, showed that it contained nothing we had not obtained from the shallower depths between the surface and one hundred fathoms.

In a haul with the deep-sea Tanner net, made at 1.50 P. M., five miles off Havana, in a depth of seven hundred fathoms, we towed for twenty minutes at a depth of three hundred fathoms. There was nothing found in the closed part of the net. There was a strong southeast breeze, so that we obtained comparatively little in the surface tow-net except a few pelagic algæ, Diphyes bells, and Copepods, while in the part of the tow-net which remained open all the way from the 300 fathom line to the surface we brought up a mass of pelagic stuff, consisting of Ctenophores (probably species of Idyopsis and Eucharis), of two species of Diphyes, of floats and tasters of Rhyzophysa, of masses of Copepods, of Schizopods, three species of Salpæ, many specimens of Doliolum, a few

Alciope, annelid and crustacean larvæ, Brachiurans, as well as Macrurans, and several species of Pteropods, the whole tow mixed in a broth of pelagic algæ, in striking contrast with the paucity of the pelagic fauna and flora at the very surface.

On another day, at 2.10 P. M., we made some hauls near the same locality, off Morro Castle, in seven hundred and forty-nine fathoms. We towed at two hundred and fifty fathoms for twenty minutes. The open part of the net contained many Sagittæ, Copepods, bells of Diphyes, pelagic algæ, Thysanopoda, Hyperiæ, Limacina, and crustacean larvæ. There was neither animal nor vegetable life in the lower closed part of the net. The water was smooth, a very light wind only having slightly ruffled the surface. The surface tow-net contained many fragments of Ctenophores, masses of Copepods, of Schizopods, of Macrurans and Macruran larvæ, as well as annelid larvæ, Sagittæ, Salpæ, Doliolum, Autolytus, Collozoum, and great numbers of pelagic algæ.

A second haul was made about an hour later at the same locality. We towed for twenty minutes at a depth of one hundred and fifty fathoms. This time the closed part of the net contained a few annelid larvæ, some Schizopods and Copepods, all of the same species we had found on the surface. It also contained specimens of Limacina and Styliola. None of these were in the surface tow-net, but they had been obtained from the surface on another occasion. In the open part of the net, which had remained open from one hundred and fifty fathoms to the surface, we obtained the same Pteropods which were found in the closed part of the net; also the same Copepods and Schizopods, as well as the same annelid larvæ. In addition, the open part of the net contained bells of Diphyes, fragments of Ctenophores, Salpæ, Doliolum, crustacean larvæ, Collozoum colonies, and pelagic algæ.

On comparing the amount of material obtained in the closed part of the bag from towing twenty minutes at a depth of one hundred and fifty fathoms with the amount obtained at the surface in a tow-net dragged during the same length of time, we cannot fail to be struck with the poverty of the deeper haul as compared with the abundance of the haul made at the surface. After hauling in about thirty fathoms of the wire, we brought up a fine specimen of Rhizophysa. At six in the afternoon we towed the Tanner net for twenty-five minutes in one hundred fathoms near the same locality. The wind had sprung up somewhat, so that the surface tow-net contained practically nothing; everything had been driven from the surface. In the closed part of the bag (towed at one hundred fathoms) we found Doliolum, Copepods, Sagitta, and Schizopods, all of species identical with those collected in the open part of the bag dragged through the belt extending from one hundred fathoms to the surface. It contained in addition some large Schizopods and Sagittæ, Tomopteris, Salpæ, Diphyes, Pteropods, tasters of Rhizophysa, and crustacean larvæ.

We hoped also to have made a large number of deep-sea soundings; unfortunately the trades were unusually heavy during the greater part of our visit to the Bahamas, greatly interfering with such work on a vessel no larger than the "Wild Duck," — one hundred and twenty-seven feet on the water line. For the same reason, the number of deep-water pelagic hauls was also much smaller than we had expected to make, as in a heavy sea the apparatus would have been greatly endangered. This was something of a disappointment, as the yacht was specially equipped for this work, and I had hoped, with the assistance of such skilled draughtsmen as were my assistants on this trip, Messrs. J. H. Emerton and A. G. Mayer, to accumulate a large series of sketches of pelagic types. It is a very different thing working at sea in a small yacht like the "Wild Duck," from working in such vessels as the "Blake" and the "Albatross," fitted up with every possible requirement for deep-sea work. The "Wild Duck," on the other hand, was admirably adapted for cruising on the Bahama Banks, her light draught enabling her to go to every point of interest, and to cross and recross the banks where a larger vessel could not follow. I am under the greatest obligations to my friend, Mr. John M. Forbes, for having so kindly placed his yacht at my disposal for this exploration.

The Bahamas (Plates I., VIII., IX., and X.) naturally divide themselves, first, into sunken banks like the Navidad, Silver, and Mouchoir Banks; next, islands occupying the whole or nearly the whole summit of the banks from which they rise, like Watling, Rum Cay, Conception, Samana, Mariguana, the Plana Cays, Inagua, Little Inagua, and the atoll of Hogsty; then, banks having the semblance of atolls, like the Crooked Island and Caicos Banks, which are fringed by low islands forming a crescent with an open lagoon or flat between its horns; next, Salt Cay Bank, which from its structure holds a position intermediate between the group of sunken banks like Navidad and that resembling the Caicos Bank; and finally, such composite banks as the Little Bahama and Great Bahama Banks, with the characteristics of a combination of banks resembling all the others.

Darwin, in his account of the reefs of the West Indies,[1] assumes "that large accumulations of sediment are in progress on the West Indian shores, . . . especially of the portion north[1] of a line joining Yucatan and Florida. The area of deposition seems less intimately connected with the *débouchement* of the great rivers than with the course of the sea currents, as is evident from the vast extension of the banks from the promontories of Yucatan and Mosquito." Darwin considers the isolated banks, such as the Misteriosa Bank, the bank off the northern point of Old Providence, Thunder Knoll, and others of various dimensions, to be "composed of sand firmly agglutinated, with little or no coral." He considers their steep slopes as characteristic of similar banks "in all parts of the world where sediment is accumulating, . . . the banks shelving very gently far out to sea, and then terminate abruptly. . . . The form and composition of the banks in the middle parts of the West Indian sea clearly show that their origin must be chiefly attributed to the accumulation of sediment; and the only obvious explanation of their isolated position is the presence of a nucleus round which the currents have collected fine drift matter." Further he says, "There cannot be any doubt that the Mosquito Bank has been formed by the accumulation of sediment round the promontory of the same name." And, finally, he says that the origin of the Bahama banks "is easily explained by the elevation of banks fringed on their windward side by coral reefs." But he modifies this assertion by stating that the Bahamas, as well as many of the submerged banks of the West Indian sea, "have been worn down by the currents and waves of the sea during their elevation."

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[1] Coral Reefs, 3d edition, London, 1889, Appendix, p. 266.

From what we have learned of the geology of the West Indian seashores, there is nothing to confirm Darwin's views of the formation of great accumulations of sediment against the promontories of Yucatan or of Mosquito. The great submarine plateaus off those coasts consist of the seaward continuation of their shore strata, and not of accumulations of sediment. Whatever loose particles compose the bottom on these plateaus are due to the remains of the animals and plants thriving upon them, and flourishing to an unusual degree from the mass of pelagic life brought to serve them as food by the prevailing currents and winds. The currents, while they bear but little sediment in suspension, on the contrary carry along a pelagic fauna and flora unsurpassed in richness, but which supplies a comparatively small amount of material towards the building up of the submerged West Indian banks compared to that furnished by the carcasses of the animals and plants fed by this pelagic material, and the remains of which supply the great bulk of the deposits which go to build up these banks.

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[1] This must be a misprint for "east."

Substituting older limestones in place of the oceanic deposits which Darwin imagines to have been made on the shores of the West Indian sea, and it seems to me that he has himself in his account of the coral reefs of the West Indies, the substance of which I have quoted above, given an admirable summary of the possible condition of the substructure of coral reefs in areas where it did not appear that his theory furnished a satisfactory explanation of the facts.

The following report must decide how far the explanation given by me satisfies the conditions of the coral reefs existing in Cuba, the Bahamas, Florida, the Bermudas, and other West Indian areas.

The plateau upon which the Bahama Islands are situated is connected with the shore plateau (the "Blake Plateau") of the east coast of the United States, extending in a triangular shape from Cape Hatteras to the Little Bahama Bank.[1] Its western face is separated by comparatively shallow straits from Florida; these become deeper as we proceed south, and their depth increases regularly towards the westward to the deepest points between Cape San Antonio and Yucatan.

The Bahama Plateau is separated from Cuba by the Old Bahama Channel. It gradually increases in depth eastward as we go from three hundred fathoms off Cay Frances to its greatest depth, over one thousand fathoms, off Diamond Point, between it and Boca Guajaba. (Plates I. and VIII.) The plateau itself slopes to the eastward at its northern termination, as is well shown also from the line of soundings to the north of the Little Bahama Bank parallel with it, and along the axis of the Northwest Providence Channel separating it from the Great Bahama Bank.

The relations of the banks to the eastward of the Great Bahama Bank are best seen from an examination of the hydrographic sections on Plates IV. and V., and of the charts, Plates I. and VIII.

In attempting to explain the formation of the Straits of Florida, we should remember that, in addition to whatever part the Gulf Stream may have played in cutting them out, on the Florida[2] side of the straits the land was nearly stationary during the time of the formation of the Florida reefs, while on the Cuban side the coral reefs have been elevated, and on the Bahamas the reefs now flourishing are in a region where there has been considerable subsidence, increasing as we pass eastward. If these movements of the Bahama Banks and of the land on their sides were synchronous, they must have produced considerable warping of the surfaces enclosed within the area explored by the "Wild Duck."

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[1] See charts, Figures 56 and 176, "Three Cruises of the Blake."

[2] See Suess, Antlitz der Erde, Vols. I. and II., Chapters X. and XVII.

Mr. William H. Tillinghast has published some "Notes"[1] on the historical hydrography of the Handkerchief Shoal, "thinking that an examination of old maps might reveal a change of condition in the shoals since the time of the discovery of the Bahamas. . . . They throw more light on the condition of the cartography of the West Indies than on any physical changes among the islands."

An examination of the earliest charts of the Mouchoir Bank enumerated in the "Notes" which Mr. Tillinghast was kind enough to make with me at once showed the impossibility of their having been based upon actual surveys. On the chart of Thomas Jeffreys (1775), the Windward Passage from the east end of Cuba and the north part of Saint Domingo, there is a legend regarding the Banc du Mouchoir Quarré: "This bank is very little known. The soundings are taken from an English chart." It contains nine islands. On writing to Captain W. J. Wharton, R. N., Hydrographer of the Admiralty, regarding this English chart, I was kindly informed by Staff Commander Tizard that there appeared to be no earlier chart at the Hydrographic Office than that of 1775 by Thomas Jeffreys.

It is most natural that in those days, when computations for longitude were comparatively inaccurate, that in a region where the currents are most variable and often quite strong, the positions assigned to shoals and islands should be very inaccurate.

Even at the present time it is most difficult, owing to the varying strength of the currents, to pick up the position of well known banks, and still more difficult to find banks like that on which the "Superb" and "Severn" anchored, the position of which never was accurately fixed. But little importance can be attached to islands as shown on an old chart. On banks like those to the eastward of Turk's Islands (Mouchoir and Silver Banks), where there are many rocks awash, it is not impossible that patches of rocks awash should have been mistaken for islands by ordinary observers, and so marked on the charts.

But when we come to actual surveys, such as those of Count de Chastenet-Puységur (1787), who cruised over the Silver Bank and Mouchoir Quarré and took a number of soundings, we get a fairly accurate account of the aspect of the shifting bottom, of the rocks awash, and a series of quite characteristic soundings, but no islands are reported or plotted on the shoals.

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[1] Library of Harvard University, Bibliographical Contributions, No. 14, 1881.

With the exception of the changes in the distribution of the sand bores there are only some unimportant modifications of the topography of the islands recorded. Since the careful surveys of 1834, no changes of any consequence have been detected in the configuration of the land; so that we are warranted in assuming that the configuration of the Bahamas as we now know them does not differ materially from that of the Y$^{as}$ de los Lucayos as they were first discovered by Columbus. The character of the forests alone has been greatly modified since the advent of Europeans.

The large scale charts of the region we explored in the "Wild Duck" are the British Admiralty Charts, Nos. 393, 659, 1256, 2579, and 2580, and the five Charts of the Bahamas, Nos. 399, 1496, 2009, 2075, and 2077. The deep-sea soundings are in the main those taken by the officers of the United States Coast Survey and United States Fish Commission, in addition to a few lines derived from soundings taken by the United States Navy Department and the steamers of private companies engaged in the laying of submarine cables.

The charts of the United States Hydrographic Bureau covering the same field are Nos. 373, 944, 946, and 947, and for the Bahamas, Nos. 26 a, b, c, d. Also the United States Coast Survey Chart of the Atlantic Coast from Cape Hatteras to Key West, scale $\frac{1}{1,200,000}$, as well as the charts of the Florida Reefs, Nos. 166, 167, 168, and 169. For the smaller charts and plans, and other charts of the West Indian and Caribbean districts, referred to in this Report, see the Index, and the chapters on the Hydrography of the Bahamas, page 139, and on the Coral Reefs and Banks of the West Indian and Caribbean, pages 145 and 160.

# THE GREAT BAHAMA BANK.

**Plate I.**

The Great Bahama Bank, by far the largest of the group, is irregularly V-shaped; it extends four hundred miles from northwest to southeast, and its greatest width is about two hundred and fifty miles. The western face, swept by the Gulf Stream, is slightly convex, and curves round to the southeast and south, forming the northern edge of the Old Bahama Channel. It then forms the edge of a great bay at the eastern extremity of the channel, extending northward and eastward, and terminating in a blunt projection, the Columbus Bank. From the eastern extremity of this bank the edge of the Great Bank runs north, and is protected by a line of low islands making a sweep which terminates in the southern point of Long Island. The island is the easternmost projection to the west of Exuma Sound, a deep gulf separating the eastern face of Great Bahama from the edge of the bank which extends northward from Great Exuma to the western spit of the southern part of Eleuthera.

The northern face of the western shank of the Great Bahama Bank runs nearly east from the Gulf Stream. It has, like the western side, but few fringing islands. Upon the eastern edge of the western shank of the bank are the Berry Islands. From their southern line the edge of the bank runs in a curve to the west edged by the Joulter Cays, which run into the northern extremity of Andros. This island, the largest of the Bahamas, forms the western edge of the Tongue of the Ocean, which separates the eastern and western shanks of the bank. On the eastern edge of the Tongue of the Ocean there are no islands except Green Cay and a few insignificant islets. The Tongue of the Ocean is a deep pocket; the extension of its eastern shore forms a sharp angle at New Providence, running slightly north of east to the extremity of Eleuthera. This edge of the bank is flanked by New Providence and a series of narrow islands which separate the Northeast Providence Channel from the inner bank. Eleuthera forms the northern part of the eastern face of the Great Bahama Bank; its southeastern spit is united to Little San

Salvador by a shallow narrow bank, which in its turn is connected with the northern extremity of Cat Island. The latter island forms the eastern side of Exuma Sound and the most easterly point of the Great Bahama Bank. We may now proceed with the description of the islands, beginning at New Providence and taking the eastern shank of the Great Bahama Bank first.

## New Providence.

**Plate X. Figs. 2, 3; Plates XV. to XX.**

Although the island of New Providence is not one of the largest of the Bahamas, yet the character of its surface varies greatly, and it is of sufficient size to give an excellent epitome of the features which probably characterized the land which once must have covered the greater part of the Great Bahama and Little Bahama Banks.

New Providence occupies the northwest corner of that part of the bank lying between the Tongue of the Ocean and Exuma Sound, its western extremity probably extending nearly as far out toward the edge of the bank, as is indicated by the outlying islands to the west, which were perhaps once a part of it. The sea has encroached but little upon its northern shore, except near the entrance to Nassau Harbor, where a few small islands to the west of the entrance show its former northern extension, and indicate that the same causes, together with the subsidence of the bank, have separated it from Hog Island.

The 100 fathom line is quite close to the north shore of the island, as well as to the western extremity, a depth of one hundred and fifty fathoms being reached within five hundred feet from the southwestern extremity of the island.

Hog Island, Athol, and Rose Island to the east, as well as the small outlying islands to the west of the entrance of Nassau, constitute the outer line of æolian hills which were separated from the ridge upon which Nassau is built by a valley, now the harbor of Nassau. It is evident, from an examination of the Nassau ridge, that it is of æolian formation, consisting of sand dunes closely packed together and heaped up one upon another. The outer hill, called Hog Island, the land which makes the breakwater of Nassau Harbor, is much lower, and runs parallel with this in a general way. The valley which separated the two outer ranges now forms Nassau Harbor, and its continuation to the eastward is the channel which leads to Cochrane Anchorage and to the parts of the Great Bank lying between Nassau and Eleuthera. The harbor owes its existence in part to the general subsidence of this part of the Bahamas, which has sunk the valley between Hog Island and Nassau Hill as much as seventeen feet below low-water mark; while the Grantstown plain to the south of Nassau Hill (Plate XVI.), extending to the next range, is still a few feet above high-water mark. A slight subsidence would separate Nassau Hill from the rest of New Providence and form a second range like Hog Island to the north of a large bay (Grantstown plain), cutting off the southern part of the island.

This ridge extends westward beyond Fort Charlotte from the point on which Fort Montague is built. From the Caves to the western entrance of Nassau Harbor the north shore of New Providence is formed by a line of hills running nearly parallel with it, and making the north side of the basin of Lake Cunningham. A broad valley stretches between it and the range of hills extending from Fort Charlotte to Fort Montague, the valley gradually opening out as we go westward from the Cave Point. The shore line itself is a long series of æolian rock sand beaches (Plate XVIII.), separated by an occasional rocky projection forming low cliffs.

The part of the island adjoining the north shore is covered principally by shrubs and trees. The flats at the foot of the hills are cultivated, and covered with sisal or cocoanut plantations.

The Queen's Stairway presents one of the finest sections of the æolian rocks of Nassau (Plate XV.); not only does the road leading up to its base pass through cuts of æolian rocks ranging from five to fifteen feet, but the so called Stairway itself is a succession of walls showing an exposure of fully sixty feet of æolian rock. This æolian rock when first exposed to the air is comparatively soft, but becomes quite hard after exposure to the action of the atmosphere.

Immediately behind the Queen's Stairway, on the southern slope of the Nassau Range, there is a fine quarry, one of a series which begins at Nassau Street and runs along the top of the range to the eastward of the Stairway. About one third of the way up the hill there is also a large abandoned quarry, showing the structure of the æolian rock. A few smaller abandoned quarries are found near the base of the hill, in which the exposed faces differ in no wise in character from those of the other parts of the hill. The same was found to be the case in the street leading from the main street to the Queen's Quarry, the nature of the exposed faces being everywhere the same.

The æolian rock faces as exposed in the quarries are in striking contrast with the harder rock surfaces exposed in the low ground between the Nassau Range and the next range on the Grantstown road. There we find the æolian rocks of the surface coated with a hard ringing layer, and modified to a great extent by the intercalation of amygdules of red earth, which give to the rocks the appearance of an indistinct conglomerate.

At the foot of Nassau Street, twelve to fifteen feet above high-water mark, the vertical wall (ten feet high) of the back of the quarry also plainly showed lines of æolian deposit. On the way up the street there are other quarries which have been abandoned, and excavations for buildings showing the same structure. The quarries at the top of Nassau Street are being worked, and fine vertical faces could be examined there fully twenty feet in height, which showed on the whole face the same æolian structure so plainly seen at the foot of the same street, and at some other points of a still lower level, below high-water mark. The whole of the ridge forming the first hill back of the harbor of Nassau is evidently of æolian formation. Its highest point is about one hundred feet.

To the eastward of Fort Fincastle there are other old quarries, the exposures showing the irregular lines of wind-blown deposits. Wherever streets have been cut through the hillside as trenches, the same lines are visible on the faces of the side slopes. The æolian rock is used as building material throughout the Bahama Islands. It is either quarried from the surface in rough blocks from accessible faces, or regularly quarried, as at Nassau and Green Turtle Cay, by cutting narrow vertical channels five to six feet in the face of the vertical cliff exposures. A similar cut is made parallel to the face. The blocks thus laid off are then sawed in columns, and these in their turn sawed into blocks of the size wanted for building purposes. Imbedded in the rock faces of this quarry, and in the fragments scattered about, we found a number of land shells, quite similar to those still living. Mr. Dall has kindly prepared for the Bulletin a short account of the species collected.

Through the mass of the exposures tubes were scattered irregularly, formed from the decayed roots of bushes, grasses, and other plants which covered parts of the sand dunes while they were forming.

To the westward of Nassau the shore of New Providence is marked by a succession of beaches and æolian rock outcrops, and outlying cays, which once must have been short lines of hills more or less parallel to the principal hills on the north side of New Providence. They were separated from one another by low wooded flats, very similar to those now stretching at the base of the existing hills, but which by subsidence and erosion have been changed into the narrow channels separating the outlying cays from the main island of New Providence. In some instances there has been an accumulation of recent shore coral rocks, flanking the hills and overlying the lower part of the older æolian rocks. Beyond the shore flat we cross Prospect Hill, then a second and third range of low æolian hills, and then we come upon the sink which forms Lake Cunningham (Plate X. Fig. 3). This lake fills a long valley, with its sides flanked by mangroves and with a few mangrove islands scattered on its surface. The water is slightly brackish. The vegetation outside of the mangrove belt runs into the characteristic Bahamian plants, most conspicuous among which is the so called grape tree (Plate XX.).

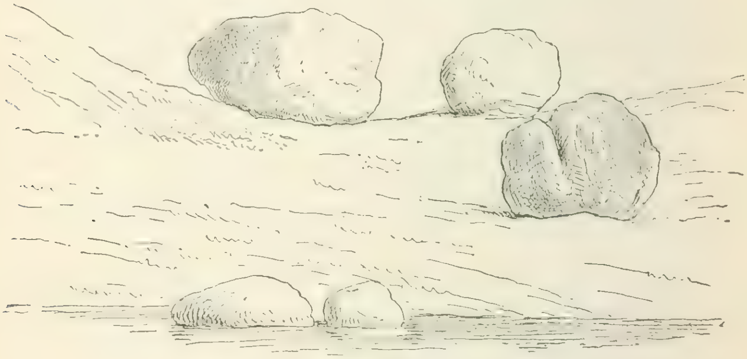
After passing the range of Prospect Hill, we come upon large tracts of pines, and in the hollows and valleys between the hills, where there is more moisture, we find a richer soil, there being more red earth in the decayed amygduloidal æolian rocks. In these low marshes and flats we find a peculiar flora, — a mixture of pines and groves of palmettos quite similar in character to the woods in some parts of Florida (Plate XIX.). In fact, with the exception that the country is more rolling, one might imagine the scene, by its clusters of palmettos and tall pines, to be laid there; while in the more open spaces, where the forests have been burned off, whole tracts are covered with bayonet palms and magnificent brushes of young pines.

The road running west as far as Cave Point is more or less parallel with the coast, and is flanked on each side with low bushes; but the principal shrub is the grape tree. Further inland the slopes of the hills are covered with larger growths, and on the flats between the prolongation of the hills, especially in the space formed by the extension of the valley in which Lake Cunningham lies, we meet fine clusters of palmettos and tracts of pine.

The spurs of the shore hills extending in a northwesterly direction form more or less prominent spits nearly perpendicular to the shore line, according to the hardness of the rocks and their exposure to the action of the sea. The cave from which Cave Point derives its name is an old vertical cliff, which is now separated from the shore by a narrow belt of coral shore rocks which have been thrown against the æolian cliffs, and have formed also the small flat flanking the southerly extension of the spur of which Cave Point is the northern end. The cave differs in no way from the many similar caves which exist throughout the Bahamas. The cave is from twenty to twenty-five feet wide, and perhaps ten to fifteen deep in places.

From the top of Cave Point, about twenty feet above high-water mark, a road leads at right angles to the shore line to Lake Killarney (Plate X. Fig. 2). The road runs nearly level the whole way to the lake; the country is covered with pines and clumps of palmettos until we strike the mangrove swamp which forms the edge of the lake. Lake Killarney is full of mangrove islands, forming very pretty vistas between their headlands, and occupies a shallow sink between two short ranges of æolian hills, similar to the one forming Lake Cunningham.

The bluffs at Clifton, which form the vertical cliffs of the southwestern extremity of the island, are the termination of the æolian range of hills extending nearly parallel to the south shore. This range gradually recedes from the shore, and the cliffs die out and are replaced by a long beach line, which extends nearly unbroken to the southeastern end of the island. At Clifton these cliffs are eaten in more or less by caverns and fissures both to the east and west of Moss Hill, and are admirable examples of the effect of the action of the sea upon æolian rock. The constant pounding of the ordinary swell breaks off large blocks, which in their turn break into smaller blocks and are thrown up in the season of the hurricanes above high-water mark, forming a stone wall along the coast line similar to those to be seen in other parts of the Bahamas.

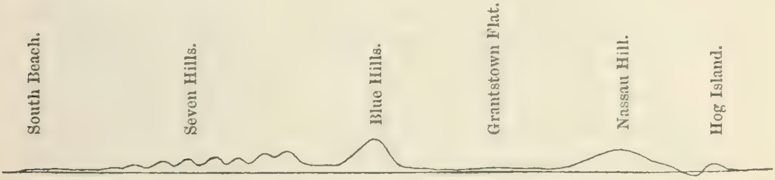

COW AND BULL.

Along this part of the shore there are many sea-holes and pot-holes, extending from the surface to low-water mark, or even below. Many of these irregular wells or caverns are from twenty to twenty-five feet deep, and when occurring in high cliffs, or hillsides farther inland, as on Long Island, from a hundred and fifty to two hundred or more feet in height, would readily account for the deep ocean-holes, one of which has been sounded to a depth of thirty-eight fathoms. These caverns would, if the islands sank to their full height, appear like ocean-holes in the general levels of the bank.

Moss Hill Bluff shows also the manner in which huge isolated rocks, sometimes twenty to thirty feet in height, like Cow and Bull on Eleuthera, near the Glass Window, may be left as fragments of hills formerly much higher, but gradually eaten away on the sides where parts of the rocks are not protected on the surface by a coating somewhat harder than that of the surface rock immediately surrounding them.

There are two bluffs to the north of Moss Hill, which now stand out like rounded knobs above the surrounding country, and which in time may appear almost like erratic boulders left high and dry, or like huge masses thrown up perhaps during a great hurricane.

The æolian rock sand from the bottom where we anchored is coarse and of a grayish color.



SECTION ACROSS NEW PROVIDENCE.

A section of the island of New Providence in a nearly north and south line from Nassau to the south shore is most instructive.

Leaving the shore at Nassau, we follow up Nassau Street, and at the quarries cross the crest of the ridge. The slope falls rapidly to the level of the extensive plain of Grantstown, which separates the shore range from the Blue Hills range. On the flat the exposed æolian rocks are greatly honeycombed and weather-worn, the whole surface occupied by pits, banana-holes, pot-holes, and cavities of all sizes, which have formed in the more or less rotten rocks of the Grantstown flat. On both sides of the road there are marshes and pools filling the depressions. It would require but slightly deeper depression to change the greater part of the mangrove marshes of this flat into lakes like Killarney, Cunningham, and other ponds which lie in deeper sinks. The greater part of the Grantstown flat is covered by low bushes (Plate XVI.), with here and there patches of mangroves.

At the foot of the Blue Hills we come upon the more or less amygduloidal rocks which usually characterize the æolian rocks a little inland, away from the immediate action of the sea, where the red earth which once filled the cavities has become a part of the rock itself. As we rise we pass into the regular stratified æolian rocks, still retaining their original structures, and only coated with a thin ringing crust at the surface. On reaching the summit and descending the hills, we come upon a low flat,[1] which separates the Blue Hills from the undulating plateau district known as the Seven Hills. These are six or seven irregular ranges, slight undulations merely, running more or less parallel with the Blue Hill range, which occupy the country between it and the south shore. These hills follow in rapid succession, and are perhaps twenty to twenty-five feet above the general line of the slope, which ends in the low flat behind the south beach. These hills become less and less prominent as we go south, and the last scarcely rises above the flat just referred to. The shore plateau immediately behind the beach is low and swampy, filled with clusters of mangroves, and when we reach the beach there are extensive mangrove flats extending some distance out (for about half a mile) from the shore line, and islets of mangroves running parallel with the line of the beach (Plate XVII.). This must evidently have been formerly a mangrove swamp similar to the one to the rear of the beach, which occupied undoubtedly a position similar to it at the foot of a low æolian hill in the valley between it and the next range, or between it and the old shore line, which by subsidence and erosion has been brought to its present level. All the way from the Blue Hills to the mangrove swamp the vegetation consisted of small pines thickly crowded together. In the more open spaces young pine shoots were starting up in all directions, and in the lower and more swampy districts between the successive ranges of hills groves of palmettos of all sizes varied somewhat the monotony of the pine barrens. Intermingling with the pines and palmettos are large tracts covered by bushes, and near the shore often prominent patches of larger trees. The pines and palmettos are affected by the proximity of the sea, being of a smaller size and growing less vigorously; while on the beach itself, and immediately behind it, we come upon the common plants characteristic of the shore line of the Bahamas.

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[1] The rock exposed upon this flat resembles the more or less rotten æolian rock characteristic of Grantstown Flat.

## New Providence to Northern Eleuthera.

**Plate X. Figs. 2, 3; Plate XI. Fig. 5; Plate XXXII.**

On passing out of Nassau Harbor, making toward Douglas Channel, we obtained the first view of the peculiar aspect presented by the low æolian hill ranges forming the outer islands of the Bahama Bank. As we passed to the seaward of Hog Island we obtained an excellent view also of the sand beaches which form the western part of the island. Similar longer or shorter sand beaches extend throughout the Bahamas on the sea faces of such islands as are more or less protected by outside rocks, outlying islets, or banks or bars, from which the material for the inner beaches is worn away by the action of the sea and thrown up on the surface of the inner island. The sand beaches may also be formed from the disintegration of the more gentle slopes on the sea face of the æolian rocks of the inner islands.

As seen from the sea, the outline of the outer islands is most characteristic. Seen slightly obliquely, such an island as Rose Island, for instance, seems made up of a series of solidified dunes falling one over another. Rose Island is a long narrow island, the highest point of which is not more than thirty to forty feet above the sea level, of about twelve miles in length. One might readily imagine from the distant outline that the whole mass of the island was moving bodily to the westward, in a series of low sand waves, under the influence of the prevailing winds. Rose Island is parallel to the range of islands of which Hog Island may be called the centre. Long Cay and North Cay form the western extension, while Athol Island makes the eastern extension. Parallel to Rose Island are Salt Cay to the west and Booby Island to the east, — the remains, perhaps, of the range of æolian hills which formed the very edge of the northern part of the bank to the eastward of Nassau, very much as Egg and Royal Islands are the remnants of the ranges of the northeastern points of the bank.

Rose Island is perhaps one of the most characteristic of the Bahama Islands. It consists of a single narrow ridge of æolian rocks, extending for twelve miles along the edge of the bank. In continuation of it, on the other side of Douglas Channel, is Booby Island, a very similar ridge. Rose Island is a low range of æolian hills, similar to those now running across New Providence; it has become isolated by the subsidence, erosion, and destruction of the land of which it once formed a part, little of which is left. At the eastern end of the island, where it is wider, a salt pond exists.

Passing into Douglas Channel, Booby Island (Plate XXXII.), a long barren line of rocks, is seen to the eastward, presenting very much the same appearance as Rose Island, with low æolian hills, but without a beach to either the sea face or the bank side of the range. The contrast of the appearance of Booby Island, as seen from the bank or from the northern side, is most characteristic. On the sea face it is one series of æolian hill slopes, piled one on top of another, while on the bank side the steeper slope of the hills has been cut away from the base nearly to the summit, leaving only a series of rounded tops on the horizontal line of the summits of the vertical shore cliffs. Booby Island is bare, with rounded summit, the whole surface of the island honeycombed more or less by the action of the sea. On both sides of the island the waves have made greater or less inroads, and have cut away the lower parts of the island, especially on the southeastern face, leaving round them a shallow bank formed of disintegrated æolian rock, on which animal life is not plentiful — having on it a few patches of Gorgonians and of coralline algæ — either on the sea or the bank face of the shoal. But as we go into deeper water, four to six fathoms, toward the steep edge of the bank, in the direction of the Providence Channel, we come upon more or less extensive patches of coral heads, separated by clear sand, which form an irregular belt of corals to twelve or to sixteen fathoms in depth along the sea face of the bank, from its northeastern extremity to the western end of New Providence.

Samphire and Upper Samphire Cays have the same general structure as Booby Island. There is perhaps a little more low vegetation on these rocks, and they appear a little greener. They are the remnants of cays which were undoubtedly similar to Hog, Rose, and Booby Islands, and which once formed long narrow æolian ranges on that part of the bank. The disintegrating action of the sea has, however, left only parts of these ranges, either as low cays like the Samphires, or the patches of small banks rising nearly to the surface on the two sides of the Fleeming Channel. In the distance we passed the western end of Current Island, a low point covered by a few trees. The point is formed of low undulating hills, of about the same height as Hog Island, and presenting the same structural features.

On our way to the Little Bahama Bank we passed again over the bank lying between Nassau and the Fleeming Channel. Through this we passed, and steered for our anchorage on the northwestern extremity of

Northern Eleuthera off Current Cut. The Six Shilling Cays and other rocks forming the northwestern edge of the bank to the eastward of Nassau are all low, bare, eaten away at the base (the remnant of the Eleuthera-Nassau land), formed of æolian rocks greatly weathered and worn; Fleeming as well as Douglas Channel being formed by the subsidence of the bank, of which the islets and cays and rocks are the higher summits and the channels the lower parts of the intervening space. As we came up to Pimlico Cay we saw an extensive belt of angular æolian rocks thrown up along the north shore of the cay above high-water mark. The north face of the cays between Fleeming Channel and Current Cut has been greatly eroded, and the rocks rounded and honeycombed by the action of the sea.

From Pimlico Cay to Egg Island round to Bridge Point there are a number of cays which have formed an outside line as it were upon the triangular extension of the bank to the northwest of Eleuthera. These cays are the outliers of the former Eleuthera land, having become disconnected from the main island. Of these cays we examined Egg Island, Northern Eleuthera, and the north end of Current Island adjacent to Current Cut. The constitution of the islands was everywhere the same, of æolian origin. The bottom on the bank where we anchored was made up of fine coral sand, with many broken shells, mainly bivalves. A strong current sweeps north or south through Current Cut according to the stage of the tides.

From the western face of Egg Island an extensive reef runs parallel to Royal and Russell Islands, from two to three miles distant, as far as Bridge Point on Eleuthera, where it sweeps across the northern extremity of Eleuthera and skirts the cays as far as the southern end of Harbor Island. The 100 fathom line runs so near the bluffs of Eleuthera, near the Glass Window, that the reef is interrupted, but reappears near James Point. From there it skirts the eastern face of Eleuthera as a fringing and barrier reef, and it extends south to meet the reef which connects Eleuthera, Little San Salvador, and Cat Island. From Eleuthera Point it extends on the west coast, but rather irregularly, as far as Bamboo Point. It appears again in patches on the west side of Powell Point Channel, to the south of the Schooner Cays, on the northern edge of the Exuma Sound Bank. From Ship Channel Cay to Wide Opening the corals on the edge of the bank are in from three to five fathoms of water, and the gaps between the cays are one mass of coral heads, with such passages as Ship Channel, Highborn Cut, Wax Cay Cut, and Wide Opening leading from Exuma Sound on to the bank.

In the passages — such as Douglas Channel and Fleeming Channel — leading from the Northeast Providence Channel on to the bank, we find that coral heads extend into three to four fathoms, and may be found even at less depth. But the heads are not vigorous, and do not compare with those growing on the sea face of the banks. They occur everywhere on the banks in proximity to the open waters of the deep channels, forming more or less extensive patches, such as are known near Nassau, between Hog and Athol, as the Marine Gardens.

On striking the open bank itself, beyond the influence of the fringing cays, one cannot fail to be struck with the poverty of the fauna and flora upon this great expanse of disintegrated æolian rocks. We found almost nothing upon the bank in the line extending in a general way parallel to the northern edge, from Douglas Channel to the Glass Window on Eleuthera; here and there were to be met patches of Millepores or of Gorgonians, or a few sponges, very few mollusks, small clusters of Zostera and of coralline algæ, and a few broken sea-urchins and shells, and here and there a Crustacean or a Holothurian. The bottom was plainly visible as we steamed along, the ground occupied by animal or vegetable life presenting a different coloration.

The long cays which are scattered upon the northeastern extremity of the Bahama Bank to the northwest of Eleuthera are edged, as seen coming from the north, by very low cliffs of æolian rocks breaking in here and there on the otherwise continuous shore line. The north line of cays are fairly sheltered from the violent action of the swell, owing to the width of the shallow bank which extends beyond them, and also by the line of the coral reef which fringes nearly the whole width of the bank from a depth of five or six fathoms to ten or fifteen; so that the sea is eating away but slowly the base of the shore hills of these cays.

Egg Island, on which we landed, does not differ from the typical Bahama cay. The base of the æolian hills on the south face has been beaten into diminutive vertical cliffs, which pass gradually into the rounded hill slopes of the cay. The surface of the rocks is more or less water worn, according to its distance from high-water mark and its exposure to the action of the sea.

## Eleuthera.

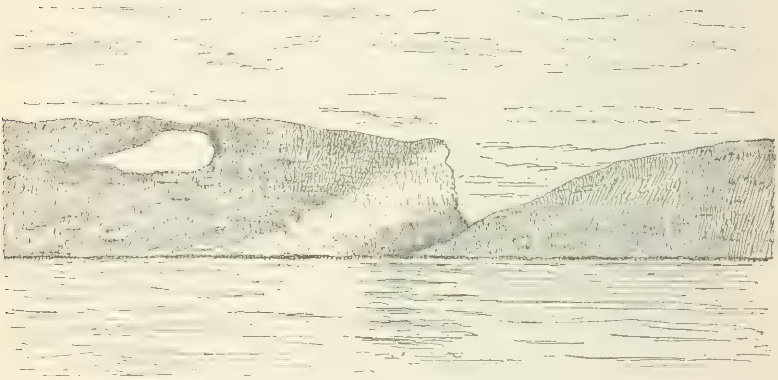
**Plate I.; Plate X. Fig. 2; Plates XXVII. to XXX.**

On both sides of the passage separating Northern Eleuthera from Eleuthera the island is so narrow that the whole surface is washed by the spray from both the eastern and western sides. The surface is free from vegetable growth, and the incessant action of the sea-water and of the rains has honeycombed the rocks from the water up to the highest ridge of the cliffs forming the eastern edge of the island. These cliffs are perpendicular, the heavy trade swells having broken off large masses of the eastern sides of the æolian hills and gradually washed them off into deep water, the 100 fathom line not being more than about a mile from the shore, and often much less, except at three or four points where the island must formerly have extended from five to six miles farther eastward, as off Savannah Sound, James Point, and the northeast bank to the eastward of Man Island. These perpendicular cliffs extend northward and southward, and form the sea face of Eleuthera. There is no shelf of any width at the base, and only along those stretches of the island where the coast shelf has any width do we find extensive patches of coral reefs forming a sort of barrier reef; as, for instance, at irregular intervals all the way between Eleuthera Point, Savannah Sound, and James Point, and again from Harbor Island to Egg Island, on the northeast and northern faces of the outside bank.

The photographs (Plates XXVIII., XXX.) will give a better idea than could any detailed description of the honeycombed surface extending north and south of the Glass Window Passage. In some cases the height of these little Gothic pinnacles is nearly three feet, and walking along the surface is very difficult. We met with similarly eroded surfaces at many other places in the Bahamas where the islands are narrow and their surface subjected to the action of the spray or surf, in addition to that of the rains in districts with a scant vegetable growth.

In the hollows formed by the disintegration of the surrounding surface there are accumulations of red earth, and there a few isolated stunted bushes begin to make their appearance. They gradually pass into larger patches as we come to wider parts of the islands not influenced by the action of the spray, where the decomposition of the surface rocks has been limited to the action of the rains. From three quarters of a mile to a mile both north and south of this barren tract, which looks more like an area covered with volcanic scoriæ, the vegetation begins again, and going south we soon pass into regions thickly covered with the same underbrush which is so characteristic of the shores of all the Bahama Islands; and inland we get patches of aloes, of palmettos, and of the forest trees characteristic of the Bahamas.

The arch of the Glass Window was evidently formed by the undermining action of the sea, which little by little disintegrated the underlying rock; finally the overlying arch gave way in part, leaving an opening known as the Glass Window, and remnants of the rocks forming the arch lining the western sides of the opening.



THE GLASS WINDOW.

Both the northeast and northwest winds act upon the southern shores of Northern Eleuthera, and are gradually eating away the outer shore shelf, forming low vertical cliffs, and leaving here and there numerous isolated rocks in from two to three feet of water, more or less water worn, and eroded or diminutive islets formed by the general subsidence and by erosion, which will gradually disappear and finally leave only the uniform flat level of the parts of the bank adjacent to the islands. An examination of the large-scaled charts of the Bahamas will show a large number of such islets and islands anywhere in this group, either on the windward or lee faces of the larger islands (see Plates IX., XII.). These different islets are now prominent, according to the height of the original hills of which they once made a part, or form shallow portions of the principal banks. The long island to the south of Savannah Sound, on the east face of Eleuthera, is an excellent example of such sloughing off (Plate X. Fig. 2).

The west face of Northern Eleuthera, as seen from our anchorage off the Glass Window, is very much eaten away into low perpendicular cliffs behind a nearly flat area of considerable extent, eastward of which rise the hills forming the eastern face of the island. As we proceed south, the western cliffs become somewhat higher (Plate XXVII.), as the western hills composing that part of the island, instead of being cut away at the base like the northern hills, have been cut away at a considerable distance inland. To the eastward of the outer western range are piled three to four, or even five, irregular rows of æolian hills, the sides of which encroach one upon another, and form more or less irregular ranges of hills according to the width of the island.

Even a casual examination of Eleuthera and of the adjacent islands to the northward and westward cannot fail to give one a very fair impression of the forces which have been at work on the Bahamas to bring them to their present condition.

Northern Eleuthera is nearly disconnected from Eleuthera by the gap forming the passage to the south of the Glass Window. Through this the sea breaks at high tide, and during a heavy swell the wash covers the path leading to Rock Harbor. The æolian hills which form the westward limits of the bay are protected from the sea by Harbor Island and Man Island. They are the inner range of hills which was once separated by a low flat from the outer range of which these islands are the remnants. With the general subsidence this flat has been changed to the shallow bay forming Harbor Island Bay. The action of the sea coupled with subsidence has in its turn formed the passage between these islands, as well as between Current Island and the western spit of Eleuthera. Similarly, George, Russell, Royal, and Egg Islands, with the adjoining rocks and islets, have become separated, and are left as the outcrops of a greater Northern Eleuthera which occupied in comparatively recent times perhaps the whole of the northeastern extremity of the Great Bahama Bank.

The action of the northwesterly and southwesterly winds along the western face of the islands has completely washed away the western ranges of hills which undoubtedly once formed a part of Eleuthera proper. The more southerly extensions now forming that part of the island from Palmetto Point to Eleuthera Point are the remnants of these ranges, the more prominent being the hills extending from Eleuthera Point to Powell Point, the outlyers to the eastward of which are the Schooner Cays, Finlay Cay, and the great sandbore bank to the eastward of the so called Middle Ground. This shifting bank we can readily reconstruct as a part of the greater Eleuthera, New Providence Island, to which I have already referred.

The condition of the western face of Eleuthera shows admirably the method of erosion, disintegration, and denudation which has taken place on the inner face of an island facing the great bank of which the part now worn away must once have been the summit surface.

Going south from the Glass Window, we keep sufficiently within sight of the land to read, as we pass along, its former history. About two miles south from the "Cove," where we anchored, begin a series of vertical cliffs, which continue almost uninterruptedly as far as Hatchet Point. They are full of holes and of small caverns, ribbed with stalactites, giving the face of the cliffs, not only here but everywhere nearly in the Bahamas, the appearance of basaltic rocks, more or less eaten away at the base. The cliffs are the remnants of the headlands, which have been worn away first, leaving only here and there a slope reaching from the inner hills to the shore. All along the west coast there is excellent sponging and fishing for large conchs. We found conch-shells and fragments of corals thrown up fully twenty-five feet above high-water mark, and lighter fragments of shells and dried stems of Gorgonians blown by the winds to the highest points of the hills on each side of the Glass Window.

Dana describes the surface of Metia, an elevated coral island which presents, I should say, much the same honeycombed appearance so characteristic of the more exposed and weathered islands and islets of the Bahamas, especially as seen at the Glass Window (see Plate XXX.). Its shore cliffs and rounded summits present a striking resemblance to some of the Bahamas. Compare the figure given by Dana (Corals and Coral Islands, page 193) with the figures I have given of the Bahama æolian hills and cliffs.

All the way from Hatchet Point to Governor Harbor (Plate X. Fig. 2) the same succession of vertical cliffs continues, with the same undulating, rolling æolian hills, perhaps a little lower behind the shore cliffs than farther north. To the south of Governor Harbor the ground falls off a good deal to Savanna Sound, and there are fewer vertical cliffs along the rest of the shore of Eleuthera extending to Powell Point. While coasting along Eleuthera we were taken at a good rate by a fresh northwester, which stirred up the bottom very extensively, and the whole sea was one mass of milky water carrying a very perceptible amount of particles of lime in suspension, derived both from the bottom and from the shores. There is to the westward of the island extending from the Cove to a few miles north of Tarpon Point a marked depression in the general level of the bank, varying from four to six fathoms in depth, with an average width of more than eight miles (Plate X. Fig. 2). This must at some time in the history of the bank have formed an extensive lagoon or flat very similar to the lakes and flats now existing on a smaller scale at New Providence.

Although from abreast of Savanna Sound to Powell Point the general aspect of the island continues the same, yet from the altered trend of the shore its outline is greatly changed, and the island widens out between Powell Point and Eleuthera Point and extends eastward to form a long, irregular triangle, deeply indented by Tarpon Bay and Rock Harbor anchorage. The low spit forming the outer barrier of the harbor seems to be of recent shore sand origin, and not to be the remnant of some wider promontory. It is similar in structure to the few beaches and spits of recent origin which here and there have been thrown up to form small lagoons or barriers across headlands in favorable localities, where they are exposed to any length of reach of wind, as this point is to the northwest winds, which often blow here with great violence.

We leave the bank by a shifting channel leading from Tarpon Point by the sand spit to the north of Powell Point, to the westward of which lie an extensive flat formed by sand bars, and a few low isolated cays, like the Schooner Cays (Plate X. Fig. 2). This flat separates Exuma Sound from the deeper water on the bank to the northward of the sound. The shifting character of this channel is well shown from the fact that, drawing eight feet of water, we passed safely over a bar marked one foot on the chart as corrected to 1882. This extensive flat, filled with numerous dry sand bores, extending from Schooner Cays on the east to Finley Cay on the north and the Sail Rocks on the south, may mark the position once occupied by the westward extension of Eleuthera Island.

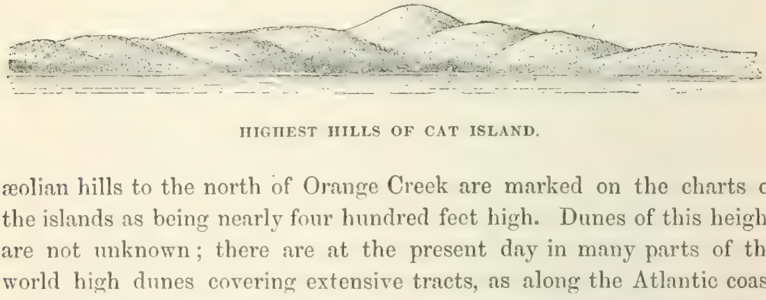
Entering Exuma Sound we skirted the Sound shore of Eleuthera past Bamboo Point to Eleuthera Point. The whole of this face of the island is low, the æolian hills not rising more than twenty-five or thirty feet in height. Near Eleuthera Point the rolling hills become slightly higher, some of them reaching forty to forty-five feet, — as Miller Hill, for instance, which is noted on the charts as forty-five feet high. There are numerous disconnected beaches on the Sound face of Eleuthera. The 100 fathom line is not more than two miles distant from the shore line, falling abruptly from the 10 to the 15 fathom line. Between Powell Point and Bamboo Point it is less than a mile off shore. The eastern extremity of Eleuthera Island at Eleuthera Point shows admirably the action of the sea in breaking through the long and narrow spit which once must have connected Little San Salvador with Eleuthera Island, and gradually reducing it to the bank which now alone forms the connecting link, after having worn away the islands first formed, the remnants of which still exist as a series of isolated islets and rocks extending to the line of breakers to the east of Eleuthera Point, while here and there a single rock may still be detected standing in the breakers.

## Little San Salvador and Cat Island.

### Plates I. and XXXIV.

Little San Salvador, and the islets and islands between it and the northern end of Cat Island, are the last vestiges of the former land extension of Cat Island, when it must have covered nearly all the space now limited by the 10 fathom line to the eastward of the island, from Hawk's Nest Point to Little San Salvador. Little San Salvador will eventually disappear. It is now low, not more than twenty feet high, and a long beach broken by six or seven rocky bluffs forms its easterly face.

Cat Island, where we anchored off Orange Creek, is interesting as having the highest land of any of the islands of the Bahamas. The æolian hills to the north of Orange Creek are marked on the charts of the islands as being nearly four hundred feet high. Dunes of this height are not unknown; there are at the present day in many parts of the world high dunes covering extensive tracts, as along the Atlantic coast of the United States, both inland and along the sea border. They often rise to heights fully as great as those observed in the Bahamas, and that from comparatively narrow beaches. On the coast of the Baltic there are long stretches of unbroken dunes for many miles, the crest of which averages from ninety to one hundred and fifty feet in height, the summits rising to one hundred and eighty feet. On the west coast of Africa, near Cape Bojador, sand dunes are said to reach a height of over five hundred feet.


HIGHEST HILLS OF CAT ISLAND.

The west face of Cat Island is a series of low bluffs and beaches. The hills become lower as we proceed south, and then rise again to form the rectangular shank of Cat Island extending from Hawk's Nest to Columbus Point. The highest hills of this part of the island are to the northwest of Columbus Point, on the western shore, near Fernandez Cay. There are a few isolated patches of reefs on the northeastern extremity of Cat Island, but none along the narrow bank formed by the 100 fathom line, extending from there to Columbus Point. To the eastward of Hawk's Nest there are patches and stretches of coral heads, forming an excellent reef harbor, Port Howe, between the Devil's Point and the Bluff.

## Nassau to Harvey Cay.

**Plate I.; Plate X. Fig. 2; Plate XXXVI.**

Passing out from Nassau to the eastward, Potter Cay divides the main channel into two parts, one of which is quite shallow. The æolian character of the low hills forming the base of the promontory at the extremity of which stands Fort Montague is well marked, and as we steam out we can see their continuation to East Point. On the other side of the channel we pass a series of low islands,[1] Hog, Salt Cay, and Athol, on the last of which stands the lighthouse. Their southern face is formed of low vertical cliffs; the vegetation upon these islands is scanty.

Dredging occasionally beyond the eastern channel, we brought up nothing except algæ and corallines; we passed a few patches of coral heads and of Gorgonians, generally opposite to openings between outlying islands which give a freer access to the water from Providence Channel. Our course lay southeast from the Porgee Rocks, and for a considerable distance we passed over a bottom nearly barren of animal and vegetable life; it consisted mainly of clean sand, with here and there a coral patch or a cluster of Gorgonians; but the farther south we steamed on the bank, the less numerous they became. The same was the case also when we crossed the bank from Nassau to the Glass Window; the patches of Gorgonians were more numerous as long as we kept in the vicinity of the line of cays extending from New Providence toward the Fleeming Channel.

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[1] It seems to me that the explanation given by Dr. Northrop (Trans. New York Acad. of Sci., Oct. 13, 1890) regarding the formation of the cays north of Nassau Harbor is not the correct one. They owe their existence, not to the coral sand which has been thrown up from the outlying coral reef, but to the denudation and erosion of an outer line of æolian hills parallel to the Nassau range which forms their basement. It is true that upon their sea face coral sand has been heaped up between the headlands of the æolian hills composing the cays, and sometimes blown to a considerable height to form broad and high beaches, as on the sea face of Hog Island, but the æolian rock underlying them crops out in all directions, especially on the south side of the cays.

On reaching the so called Middle Ground (Plate X. Fig. 2), we came upon a mass of Gorgonians and coral heads, through which our pilot picked his way by sight. This stretch of coral and Gorgonia ground did not extend far; we soon passed out of it and were back again upon the usual sand bottom, nearly bare of animal and vegetable life, with only an occasional patch of corals or Gorgonians. We next came upon the line of cays extending south of the Ship Channel, and were in plain sight of the æolian hills and cliffs of Saddle Cay and Norman Cay. The bank as we go south continues bare of animal life, no patches even of Gorgonians or clusters of heads of coral to be seen in any direction. Later we could see the vertical faces so characteristic of the western sides of the cays in the vicinity of Conch Cut, and to the south of that the æolian hills belonging to the chain of cays to the north of Harvey Cay.

Coming upon Harvey Cay, Bitter Guana Cay, and Great Guana Cay from the west, we were able to form an excellent idea of the character of the shores of the larger cays which are somewhat protected from the action of the trade wind swells. Their structure is the more striking in contrast with the outlying small low and water-worn cays which characterize Conch Cut and Rudder Cut. These low islets are mere ledges of rocks rising but a few feet above the water line, and likely to stand but a comparatively short time as a barrier to the inroads of the sea upon the larger inner cays.

Harvey Cay is itself greatly disintegrated; it is attacked by the spray and rain. There is but little vegetation upon it, and the limit of action of the sea upon its eastern face is very plain, at many places bare rocks extending close to the top of the cay. The east face of the cay is pitted from the action of the sea as far as it can reach. The cliffs of the lee shore are full of cavities and caverns, which have been exposed by the gradual inroads of the sea on the base of the æolian hills. As we steamed south, we could see the breakers throwing the sea over many of the smaller outer islets, or dashing its spray high above the summits of the high cays of the outer chain on the eastern edge of the bank. On Harvey Cay a little wild sisal grows; the more sheltered parts are covered with hard-wood shrubs, and the ordinary plants are found near the shore line. The bottom where we anchored was composed of a kind of sticky marl, — greatly decomposed æolian sand. The nature of the bottom is accurately noted on the charts, and from the examination of the many samples collected it will be quite possible to give an excellent account of its characteristics.

On our way south we attempted to reach some of the ocean-holes marked as existing near Blossom Channel. Unfortunately the sea was too rough, and it was impossible in the disturbed condition of the bottom to recognize their position.

Harvey Cay is connected with the outer cays to the south of it by a number of small low cays, half eaten away by the action of the sea, which reach to Exuma Sound. They form a series of narrow parallel lines of rocks, with passages like those of Rudder Cut between some of the cays. These islets are in every respect similar to the numerous small islets we saw as we passed through Conch Cut (Plate XXXVI.). They extend across the passage between Harvey Cay and Great Guana Cay.

## From Harvey Cay to Great Ragged Island and Columbus Bank. — The Sand Bores of the Bank.

**Plate I.; Plate XI. Figs. 3, 5; Plate XII. Figs. 1, 2, 4; Plate XXXV.**

The passage round Galliot Bank gave us an excellent idea of the alternating channels which exist between the different sand ridges running in a westerly direction from Galliot Island to the Barracouta Rocks. The navigation is entirely by the eye, and the boat is forced across the deepest part of a terminal ridge or of a lateral spur into the nearest channel. To the windward and leeward we could see on each side three or four additional bores, parallel in a general way to the two between which we were steaming. The channels and their probable depth were fairly indicated by the color of the band of water separating them. This bank is very similar to the bores to be seen on many other parts of the bank. The sand bores and sand spits separating the channels are plainly indicated by the light emerald-green color of the water, which is in marked contrast to the darker purplish color of the belts of deeper water forming the navigable channels.

Of course, where there is such constant disturbance over the bottom, and shifting of these large sand masses in accordance with the action of the winds prevailing for any length of time, as on the Galliot Bank, we were not surprised at finding the bottom bare of all animal or vegetable life.

Some of the shallower parts of the bank are practically impassable even for the smallest boats, owing to the existence of extensive stretches covered by shifting sand bores more or less exposed at low water, when they drift like æolian sand in the direction of the prevailing winds, or are run into more or less broken ridges parallel with the direction of the short seas breaking over the flats. Such tracts on the Great Bahama Bank are formed on the northeast part of the bank extending ten miles to the westward of the Berry Islands, where we find the water on the bank varying from a quarter fathom to a fathom to the westward of the cays, and extending to a line running diagonally across the bank from the Northwest Channel to Great Stirrup Cay (Plate XII. Fig. 4). Another track extends to the north and northwest of Andros, about fifteen miles to the westward of the Joulter Cays (Plate XI. Fig. 3). A similar small patch runs parallel with the southeast end of Andros for a distance of nearly ten miles, extending westward from Curley Cut Cays and rising from the great sand flat, which increases very gradually in depth as we go west, having a depth of only two fathoms fifteen miles southwest of the cays and three fathoms at a distance of twenty miles in the same direction. Extensive bores also occur to the eastward of the Beminis, and a belt of sand bores varying in width from one to five miles extends from eastward of Gun Cay to South Riding Rock, a distance of more than twenty-five miles.

There are also a number of such bores on the Mackie Bank, to the eastward of the Beminis (Plate XII. Fig. 2), and between that and the Northwest Passage another extensive tract, forming a bank of about ten miles by eight, traversed by numerous sand ridges, carrying from one and three quarters to two fathoms and from two and a half to three fathoms between them. From Orange Cay in a northerly direction as far as the latitude of the Beminis we find a number of isolated patches or banks of sand, held together by the masses of a species of Thalassia growing upon them. About twenty-five miles to the south of Orange Cay there is a narrow belt of sand ridges running nearly parallel with the 100 fathom line for a length of about eighteen miles. These banks and bores are limited to the area north of the great marl deposit to the west of Andros, which extends from a line running west a few miles north of Billy Island to from five to ten miles south of South Bight, the western limit of which varies from three to five miles from the 100 fathom line. Outside of these limits we again find the æolian sand, more or less modified by the fragments of coralline algæ or of Invertebrates which once lived upon the banks. Algæ also flourish upon the white clay or marl district; but the number of species is not so varied as upon the other kinds of bottom.

By far the most striking of the sand bore districts is the one which forms the great sweep of the southern *cul-de-sac* of the Tongue of the Ocean (Plate XII. Fig. 1). South of the cays to the southward of Washerwoman's Cut (Plate XI. Fig. 3) is a tract of about ten by fifteen miles which is a mass of sand bores, many of them dry. To the eastward for a distance of thirty-five miles they run in a southwesterly direction, at a sharp angle with the course of the 100 fathom line. In this part of the bank they are broad ridges, more or less undulating, some of them half a mile in width and sometimes twelve miles in length, often nearly dry in places, and with from one to three fathoms on the ridges, separated by broad channels with from four to six fathoms of water. Some of the wider of these channels are regularly used as approaches to the interior of the bank, and are known as Queen's, Blossom, Thunder, and Lark Channels, through which vessels bound for Cuba cross the bank, coming out either through the Man-of-War Channel, south of Flamingo Cay, or running west of the Ragged Islands and crossing the Columbus Bank. The eastern extremity of these sand bores is formed by a tract of narrow sand ridges, with deep water between them, extending some fifteen miles along the edge of the bank on the eastern face of the Tongue of the Ocean.

To the eastward of Hawk's Bill Rock there is a line of sand bores to the south of the line of small cays reaching to the centre of the west shore of Great Exuma. To the west of the north end of Great Exuma occur a series of dry sand bores, with from one to two fathoms of water between them. They trend in a westerly direction, and run north, where they join the southern bores of the Galliot Bank. An extensive series of sand bores, many of them dry, runs east from Green Cay across the bank to within about ten miles of Conch Cut. During one whole day's sailing from Harvey Cay south nearly to our anchorage off Flamingo Cay we did not come across any patches of Gorgonians or of coral heads.

The Brigantine Cays, the Barracouta Rocks, and Hawk's Bill Rocks, low cays and patches of æolian rock, are the fragments of the western extension of the northern extremity of Great Exuma.

When we reached our anchorage off Flamingo Cay, we found the bottom a mass of broken shells, of fragments of corals and Gorgonians, and covered by Nullipores. As we approached Flamingo Cay we came in sight of some of the small islands forming a part of the chain of cays which extends in an easterly direction from Flamingo Cay along the eastern curve of the bank towards the western extension of the central spit of Long Island. These cays are well rounded and weathered, presenting the usual features of cays forming the broken wall which now denotes the former extension of the Ragged Cay and Flamingo Land to the westward till it perhaps once formed part of the Andros, Lobos, Orange, and Bemini Land.

Some of the cliffs of the western face of Flamingo are high, separated by small coral and æolian sand beaches. The high coral sand beach opposite our anchorage formed the sea-wall of a small lagoon. The southern end of the beach was formed by fragments of conchs of all sizes up to nearly perfect shells, cemented together with æolian sand, fragments of corals, and broken shells, forming a splendid breccia. The shells in the lagoon of Flamingo Cay were very much smaller than specimens of the same species thrown up on the sea face of the beach.

After passing Hawk's Bill Bank we came upon patches of corals and Gorgonians, which became more extensive as we approached Flamingo Cay, the water at the same time becoming somewhat deeper and clearer, the bottom being less affected by the action of the seas due to the prevailing winds.

Flamingo Cay (Plate XXXV.) is comparatively well covered by vegetation; there are many wild guava bushes and shrubs. The æolian rocks, as seen on the two sides of the landing beach, are greatly eroded by the action of both fresh and salt water, the whole surface of the rounded æolian hills being pitted and honeycombed. The æolian rocks of Flamingo Cay are much harder than is usually the case with the æolian rocks so close to the sea-shore. The cays to the south of Flamingo are excellent specimens of æolian cays, with rounded summits almost bare of vegetation, and with surfaces pitted and worn by the action of the sea and rain upon them. Heavy seas could be seen breaking over those nearest the outer edge of the bank. The vertical cliffs of Flamingo were riddled with cavities and fissures, as were also the cliffs of the islands to the south of Flamingo, between it and Man-of-War Channel.

Steaming south from Flamingo Cay, we cross a series of bars running apparently at right angles to the trend of the cays, having from two to two and a half fathoms over the ridges, with numerous patches of coral heads and of Gorgonians. Some of the cays to the south of Man-of-War Channel were formerly inhabited; but since the destruction of the salt trade on Great Ragged Cay they have been abandoned. All except

Nurse Cay, which is quite fertile, are bare, or support at best a very scanty vegetation.

From Nurse Channel the chain of cays continues toward the Great Ragged Cays. We pass the white cliffs of Nurse Cay, with its low æolian hills forming a slightly undulating line on the horizon, separated by a narrow channel from Buenavista Cay. Next come Racoon Cay and Double-breasted Cay, all very bare of vegetation, with here and there a long coral sand beach separating the low cliffs formed by the eating away of the base of the æolian hills which form this chain of cays.

The disintegration of the formerly existing land masses, and their breaking up into smaller masses or islands or islets, and finally rocks and sunken banks, is also in great part a process not entirely due to the mechanical action of the waves. Both the æolian and coral shore rocks become most friable when saturated with sea water, so that large masses are constantly sloughed off from the base of the hills which project into the sea. These fragments of greater or less size are themselves rapidly disintegrated by the same process, resulting in a coarse sand consisting of æolian or shore coral sand, which helps to form the small beaches so frequently separating indistinct headlands marked by vertical cliffs. By this process, beaches, small bights, or diminutive harbors may be formed in the midst of faces of high or low cliffs, parts of which have been affected more than others by the action of salt water.

## Ocean-Holes.

**Plate III.**

May we not to a great extent measure the amount of subsidence which must have taken place at certain points of the Bahamas by the depth attained in some of the so called ocean-holes, as marked on the charts? Of course we assume that they were due in the æolian strata to the same process which has on the shores of many islands formed pot-holes, boiling holes, banana-holes, sea-holes, caverns, caves, sinks, cavities, blow-holes, and other openings in the æolian rocks. They are all due more or less to the action of rain percolating through the æolian rocks and becoming charged with carbonic acid, or rendered acid by the fermentation of decomposed vegetable or animal matter or by the action upon the limestone of sea water or spray under the most varying conditions of elevation and of exposure. None of them have their upper openings below low-water mark, though some of them may reach many feet below low-water level. Ocean-holes were formed in a similar way at a time when that part of the bank where they exist was above high-water mark, and at a sufficient height above that point to include its deepest part. The subsidence of the bank has carried the level of the mouth and of the bottom of the hole below high-water mark.

From the description of the strata which crop out upon the banks in the vicinity of some of the ocean-holes at Blue Hole Point, there seems to be little doubt that the stratification characteristic of the æolian rocks has been observed.

The principal ocean-holes, Blue Holes, are the following: one five to six miles from Hawk's Bill Rock; three, of eighteen, twenty-four, and thirteen fathoms, a little east of north of Blue Hole Point, each about five miles apart on a northerly line; and two, of seventeen and thirty-eight fathoms, in the extension of the line of Blossom Channel leading from the Tongue of the Ocean upon the bank.

I am able, thanks to the kindness of Captain Wharton, the Hydrographer to the Admiralty, to give three sketches of these Blue Holes, showing the character of the soundings around them (Plate III.). They are such as we should expect to obtain from any part of the cays where there are many light-holes, if sunken below the level of the sea.

At other places on the banks ocean-holes are said to exist. Among those not on the charts, I may mention a fifteen fathom hole at High Point, Andros, and a twenty fathom hole in the Middle Bight, between Gibson Cay and Big Wood Cay. Dr. Northrop has examined some of the ocean-holes of Andros, and has given a description of those he visited.[1]

Except in the case of some wells at Nassau, there has been no observation of æolian rocks at any great depth below the surface. At the Bermudas the æolian rocks have been traced *in situ* during the building of the dry dock to a depth of over fifty feet. The presence there of trunks of trees would indicate the invasion of sand dunes at some time, much as they invade the gardens of the Bermudas at the present day.

From the description of the Bermudas given by Rein, Thomson, Fewkes, and Heilprin, there appears to me little doubt that we have there repeated on the bank of the Bermudas the identical processes which have been described in this paper, and that the Bermudas and the Bahamas owe their present configuration to the same process of waste which has been going on during their subsidence; that the so called diminutive lagoons we find there are not lagoons in the ordinary sense of atoll lagoons, but are merely small pot-holes or former banana-holes which have come to be below high-water mark. Certainly there seems to have been nothing written to prove that the present configuration of the so called Bermuda atoll is directly due to the formation of the coral reefs which are still growing upon the bank, and their increase in thickness owing to the subsidence of the bank. I shall return to this subject in the description of my visit to the Bermudas.

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[1] Trans. N. Y. Acad. of Sci., Oct., 1890.

In the shallower places on the Bahama Bank the whole body of water was discolored by the presence of sand stirred up by the action of the waves, and it is only natural that in all those parts of the banks where the water is constantly rendered turbid by moderate winds we should meet with so little animal life; for Gorgonians and corals can only flourish in clear water, and even corallines cannot obtain a foothold where the ripple-marks are too frequently changed or the bottom sand is in constant motion. Between Nurse Cut and Racoon Cut very little animal life was to be seen on the bank. After passing Racoon Cut we came upon a good many patches of coral heads and Gorgonians. At the same time the water was gradually deepening to the westward, and we seemed, steaming parallel with the general trend of the cays, to be cutting across a number of sand spits about at right angles to the shore line of the cays, and trending in the general direction of the prevailing winds.

## Great Ragged Island.

### Plate XI. Fig. 5.

Great Ragged Island, the most southerly of the cays on the Great Bahama Bank, does not differ in structure or appearance from the other cays of the group. The rocks are æolian, hard, full of caverns and cavities in the cliffs of the west side, with here and there fine sand beaches between the spits of projecting rocks. At our anchorage the coral sand was much coarser. After leaving the anchorage we passed Hobson's Breakers, to the south of Ragged Island, which are all that is left of what must once have been an island of considerable size.

## Columbus Bank.

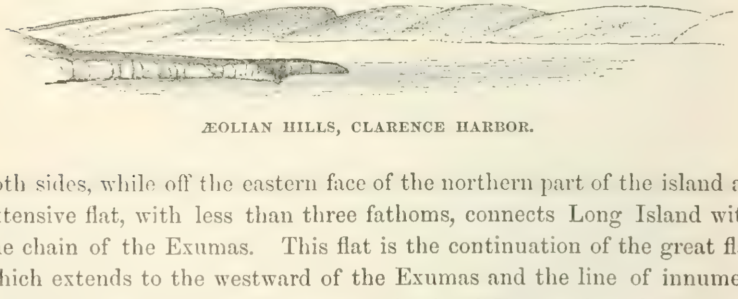
Columbus Bank, which lies to the southeast of Ragged Island, is fully exposed to the swell of the prevailing trades. Whatever cays once existed upon it have disappeared, with the exception of Cay Verde and Cay

San Domingo. The depth of water upon this bank is considerably greater than upon similar stretches of the Bahamas. Here and there patches of shallow water are dotted over its surface, but the average depth varies from seven to eleven fathoms. The sea at the time we crossed it was quite rough, and the action of the heavy swell upon that part of the bank must be quite effective.

## Long Island.

**Plate X. Fig. 6; Plate XI. Fig. 2.**

From the southwestern side of Exuma Sound extends Long Island, which projects far out from the angle of the bank. The eastern shore of Long Island is made up of a series of æolian hills, with more or less steep faces to the sea. Its highest point is one hundred and fifty feet. The island is narrow, often not more than a mile in width, varying from that to little more than three. It flanks the eastern face of the most easterly extension of the Great Bahama Bank. The 100 fathom line is generally within two miles or so of the eastern shore line. South of Clarence Harbor the island forms a long narrow spit, running southeast with the 100 fathom line within a couple of miles on both sides, while off the eastern face of the northern part of the island an extensive flat, with less than three fathoms, connects Long Island with the chain of the Exumas. This flat is the continuation of the great flat which extends to the westward of the Exumas and the line of innumerable small cays forming the western bank of Exuma Sound. On the west side of the island, opposite Clarence Harbor, the bank makes a great sweep, the outer edge, protected by the Jumentos Cays, forming a half-circle nearly to Ragged Island and the northern edge of Columbus Bank. A few small salt ponds, formed in the valleys of the æolian hills, are found near Clarence Harbor. The general trend of the æolian hills, both north and south of our anchorage, could be readily traced till the low hills disappeared below the horizon. Patches of coral are growing in the harbor, which is protected by small cays from the prevailing winds.



ÆOLIAN HILLS, CLARENCE HARBOR.

From Clarence Harbor we crossed to the west shore of the island. The salt ponds near Clarence Harbor are separated from the sea by an outer range of æolian hills. From the level of the ponds we gradually rose to the top of the second range, perhaps eighty feet above the sea level, and then gradually passed down the sea face of the slope of the last æolian range to the low western shore. Here we found a long, narrow lagoon, Salina Flat, formed by the throwing up of a low outer bank of æolian sand recently washed up and inclined at a slight angle to the sea. The lagoon, which skirts the western shore of the southern part of Long Island, is about twenty-five miles in length, extending to the southern extremity of the island. To the northward, what is now a flat must have been a wide lagoon; only a part of the southern end of the bank which once separated it from the sea is now left. In fact, as will be shown later, Long Island, with the string of islands extending north of Exuma as far as Ship Channel at the north end of Exuma Sound, and the line of cays forming the curve of the southeastern face of the Great Bahama Bank as far as Columbus Bank, are the remnants of what must once have been an extensive island. This island gradually became separated, first into a series of islands closely packed together, and later, by greater subsidence, into the innumerable islands now forming the eastern edge of the Great Bank, the islands and the Great Bank itself being all that now attest the existence of the island or islands which must once have covered the bank inside the 10 fathom limit.

Long Island is noted for its many caverns. On the road across from Clarence Harbor to the west shore we could not fail to be struck with the many pot-holes, banana-holes, sinks, and other signs of the extensive denudation to which the æolian limestone rocks forming the hills had been subjected. The accumulations of red earth here and there add their testimony to the extensive action of rains, which must have carried off the surface of the hills as they percolated through the fissures of the rocks and forced their way, little by little, through the porous mass, to form the numerous and often extensive caverns which are met with in every direction.[1]

In many parts of the island we passed through forests with trees of quite a respectable size, such as lignum-vitæ, pidgeon plum, tamarinds, and the like, giving us an idea of the fine forests which must have covered some of the islands at the time of their discovery by Columbus, and in marked contrast to the pine-covered cays of Andros, New Providence, and the Little Bahama Bank.[1]

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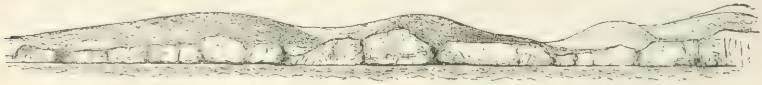
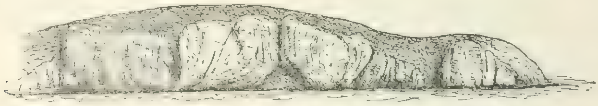
[1] Perhaps the most extensive caves of the Bahamas are those of East Caicos, described by Sharples (Proc. Boston Soc. Nat. Hist., XXII. 247, 1883).

From Cape Verd north the coast of Long Island is formed by low rounded æolian hills with gentle slopes to the eastward; it then passes into much higher hills, the base of which is formed by vertical cliffs of æolian rock, extending to the southern extremity of the opening of Clarence Harbor. To the north æolian hills of varying heights succeed one another, flanked to the eastward for almost the whole length of the island to its northern extremity by vertical cliffs full of holes and caverns. At a short distance south of Cape Santa Maria these eroded cliffs are quite striking.



ÆOLIAN HILLS AND CLIFFS, SOUTHERN PART OF LONG ISLAND.



ÆOLIAN CLIFFS SOUTH OF CAPE SANTA MARIA.

At the landing place the shores of Clarence Harbor consist of recent coral sand strata, dipping slightly to the sea. The summit of the ridge of one of the islands forming the outer barrier of the harbor, say twenty-five feet above high water, was formed of æolian rocks; on the inside, round the base of it, shore coral deposits had collected, which were exposed in the flats between the æolian hills forming the outer line of the harbor and the shore of the island. On the summit of the outlying islands we observed many huge angular blocks similar to those which are thrown up by hurricanes and line the outer shores of so many of the islands of the Bahamas.

We were able on this island easily to observe how the sea undermines the æolian rocks. Huge rocks are thus broken off from the sea face, fall into the sea, and are in turn broken into smaller blocks, either as they crumble from the fall, or by the subsequent action of the sea as they lie piled up just as if the base of the hill had been blasted; and subsequently, at times of violent storms or of hurricanes, these huge masses are hurled inland and deposited far above the ordinary high-water mark. All the way along the sea face of Long Island we passed large masses of gulf-weed, many of these patches more than twice the size of the yacht.

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[1] See List of Plants collected in the Bahamas by A. S. Hitchcock (4th Ann. Rep. Mo. Bot. Garden, 1893).

The difference in the aspect of the vertical cliffs in different parts of the Bahamas is very marked. If formed at the base of the gentle windward slope of the æolian hills, they are low and of very uniform height, especially if that face is the bank face of the island; but where the lee face of the hills — lee when formed — is also the sea face, the cliffs are on the steeper slope of the æolian hills, are far more irregular, and their height varies greatly, according to the height of the hill which is attacked and the distance inland to which the action of the sea has reached.

The corals do not form a regular reef off the east face of Long Island.

## The Exuma Islands.

**Plate X. Fig. 5; Plate XI. Fig. 1.**

To the west of Cape Santa Maria, Long Island has disappeared, leaving only a shallow bank flanking it for its whole length and connecting it with the Exuma Islands. From the central part of the western line of these islands extends a long, narrow spit, the only mark of the former extension of Long Island in that direction. It must have been a continuous shore, forming a great curve, indicated now by the row of islets and rocks which flank that part of the bank, extending in an unbroken line to Flamingo Cay, and from there by Seal Cay and the islets running to the north of Columbus Bank from the Ragged Cays as far as Nurse Channel.

Great Exuma is the largest fragment remaining of the land which once formed the eastern edge of the bank flanking the west side of Exuma Sound. Like the many islands, islets, and rocks extending northward as far as Ship Channel, it is built up of æolian rocks. Georgetown, the principal port of Exuma, lies upon a long inland sound studded with islands, and sheltered from the outer sound by a series of low outlying islands which form a barrier against the force of the trade swell, which gains considerable force over the forty miles or more of sea-way from the eastern side of Exuma Sound. These outlying islands are themselves gradually being eaten away, and were once also a part of the greater Exuma land, which has little by little become dismembered by the action of the sea upon the subsiding æolian hills. In the inner sound, which extends for many miles southward and northward of Exuma Harbor, and forms one of the prettiest stretches in the Bahamas, there are many diminutive cays, isolated rocks of all sizes, with rounded ridges undermined at the water's edge and ready to topple over and disappear. The æolian rock, kept constantly wet, becomes soft and readily crumbles, and is washed into æolian rock sand. The whole floor of the harbor is covered with fine sand of this kind, and the harbor is gradually filling with material derived from the wash of the windward row of outer islands. Off Exuma, between it and the northern end of Long Island, the edge of the bank is comparatively wide. The British Admiralty Chart, No. 393, shows admirably the gradual wasting of the land which has taken place to form the inner sound.[1] There was comparatively little animal or vegetable life on the floor of the harbor where we examined it. On leaving Exuma we sounded at short intervals, and found the sea slope of the bank much less steep and more gradual than that of other faces we had explored.

## From Conch Cut to Green Cay.

### Plate XXXVI.

From Exuma Harbor we steamed northward to Conch Cut, keeping as close as was prudent to the outer line of cays, which all showed indications of great erosion. On the northern extremity of Great Exuma the æolian hills are closely packed, and reach a height of one hundred and fifty feet. The islands of Lee Stocking and Great Guana present the usual features of æolian hills attacked by the sea at the base of the longer slope. The smaller cays are bare, while even on Exuma and the larger cays the vegetation is far less luxuriant than we might expect from the size of the islands.

Passing through Conch Cut to enter upon the bank on our way to Green Cay, we were struck with the number of small islets, which form a wide protecting belt against the encroachments of the sea. The islets are all exposed on the lesser slope of the æolian hills to the action of the trade swells, while the steeper face has been attacked by the shorter, sharper waves reaching across the bank, and undermining the western faces of the islets to an extraordinary degree. The solvent action of the sea water has also undoubtedly played an important part in producing the fantastic shapes which some of the islets and isolated rocks have assumed; so that by this combined action a wide shallow bank has been formed which connects all these islets together, leaving only such entrances as Conch Cut, Wide Opening, and Wax Cay Cut for the passage of craft of shallow draft. The light green color of the bank connecting the islands indicates very markedly its position as contrasted with the deeper waters of the passages and of the outer sea edge of the bank. The larger cays are flanked on the western face by white sand beaches, formed by the rapid disintegration of that side of the cays.

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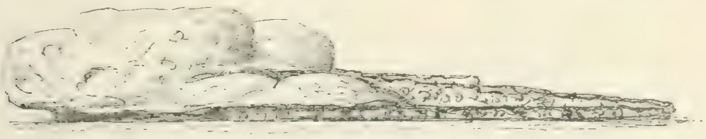
[1] See also U. S. Hydrographical Charts, Nos. $26^b$ and $26^c$.



WATER-WORN ISLET, CONCH CUT.

All the way across the bank, from Conch Cut to Green Cay, we found but little life upon the bottom; there were no patches of weeds or of Gorgonians, the bottom being everywhere composed of coarse æolian sand. But when about two to three miles off Green Cay, patches of coral heads and of Gorgonians begin to appear, and become more numerous as we approach the western edge of the bank forming the eastern side of the Tongue of the Ocean. The absence of animal and vegetable life upon the bottom of the interior of the banks is undoubtedly due to the constant shifting of the coral sand from the action of the sea. At moderate depths of one to three fathoms we could everywhere see that action plainly indicated by the presence of ripple marks. In the shallower parts of the banks this action forms great sand bores, which, exposed to the action of the winds, also tends to increase them in size in the direction of the prevailing winds. To the eastward of Green Cay we could see such a great sand bore, seven feet high, forming as it were a cay consisting of nothing but a constantly shifting tract. In many localities on the banks these great sand bores have assumed quite definite positions, which they retain, merely shifting north or south or advancing eastward or westward within narrow limits. At our anchorage off Green Cay the bottom consisted of fine hard coral sand, fairly well covered with coralline algæ.

## Green Cay.

### Plate XXII.

The western extremity of Green Cay itself is the termination of one of these shifting bores, and its frequent changes of position and dimension are known to every skipper who anchors off its shores. Green Cay has been extended by this sand bore to the very edge of the plane where the sudden drop in depth beyond the 20 fathom line takes place. The æolian rocks of Green Cay crop out at the eastern edge of this sand bore. Against these outcrops the bore rests, and in some places has completely overwhelmed them. At the eastern extremity of the western spit a mass of blocks of æolian rock has been piled up by some hurricane. On Green Cay we find the same pupæ so characteristic of all the Bahamas. The vegetation reminds us of that found on Eleuthera along the shore line. The principal mass of Green Cay, which rises to a height of sixty feet, is of æolian origin; but the extent of the cay is greatly modified by its being a buttress for the sand bores which extend from it both to the westward and eastward. Green Cay is marked among the Bahamas for the combination it presents of sand bores and æolian rocks, and shows how some parts of the banks themselves may have been formed of movable bores at certain stages of their subsidence, when masses of sand large enough to become affected in their movements by the action of the sea and of the winds had accumulated from the disintegration of fixed nuclei of æolian rocks. It is very easy to imagine such a process as we saw going on at Green Cay to have been an important factor in connecting adjoining hills or in filling low valleys between neighboring islets. Green Cay is the only cay left to indicate the former existence of the land which once extended round the edge of the Tongue of the Ocean all the way from New Providence to the islets to the south of Andros, parallel with the line of the 100 fathom soundings, which now alone indicate its probable original outline.

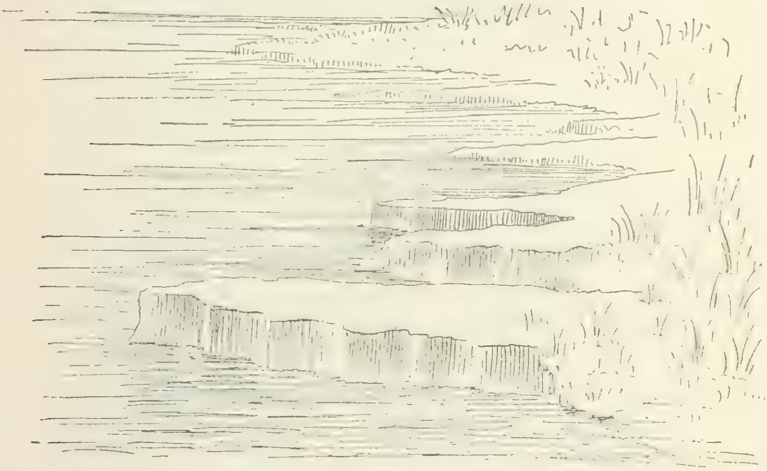
## Andros and the Western Part of Great Bahama Bank.

**Plate XI. Figs. 1, 3; Plate XII. Fig. 3; Plate XXXIII.**

From Anguila Island we crossed the Santaren Channel during the night and made for Wide Opening early in the morning. When in sight of Andros we made a haul for a specimen of the bottom, and obtained our first sample of the so called "white marl," which is marked on the charts as extending many miles west of the Wide Opening of Andros, as well as to the north and south, forming a huge triangular patch characterized by this peculiar bottom. It consists of a very fine chalky ooze, resembling plaster of Paris which has just been mixed for setting.

From our anchorage to the shore of Andros at the mouth of Wide

Opening, a distance of about eight miles, we found the bottom sloping gradually, with here and there a few blades of Thalassia. It was everywhere composed of the same marly substance, and sustained but little animal life. A few Lupas, a couple of small sharks, and the holes of a Squilla seemed to be the limit of the fauna and flora of this marly waste. On reaching the shore, we found the land, as far as we examined it, to consist of the same white marl as the bottom, but still sufficiently solidified to enable us to walk upon it. It was somewhat elastic, giving us the sensation of walking upon a sheet of India-rubber. In some places the marl was covered with a black alga, forming a thin crust, or it was often coated with a harder material composed of minute fragments of shells and of sand, giving the surface a gray appearance. On digging into the soil, we found the same white marl, more or less mixed with vegetable matter. The shore upon which we landed was at no point more than from twelve to fourteen inches above the high-water mark. The country inland seemed well covered with low vegetation, and mangroves flourished in every direction. Here and there a ridge of sand had been blown up, composed of fragments of shells and of crabs. These ridges, rising a few inches higher than the general dead level around them, formed the high ground, as it were, upon which was growing a somewhat richer vegetation, composed mainly of the same



WEST SHORE OF ANDROS, WIDE OPENING.

plants so characteristic of the shore lines of all the Bahamas. Upon these sand ridges also flourished small groves of palmettos.[1]

As we steamed northward, the low, dark line of Andros stood out in marked contrast with the intensely light-green water, extending as far as the eye could reach over the shallow bank to the westward of the island. Here and there the low line was broken by a high mangrove tree looming up like a cliff in the distance, or was interrupted by a stray line of high palmettos on some sand ridge near the shore. The edge of the island near Wide Opening is occupied by a lagoon inside the shore line, and the deep bights which characterize the island show clearly how it has little by little been eroded, then cut into halves and thirds, next into smaller cays, and finally, wearing away having commenced, has left here and there a small cay (Plate XII. Fig. 3, and U. S. Hydrographical Chart, No. 26$^a$) to the westward of the main island. As the water is quite shallow all along the west shore of Andros, its action is most feeble, and it must have triturated and ground very slowly all the shore material into the very fine and minute particles composing the "white marl" covering so large an area of the bank between the island and the Santaren Channel. This white marl looks almost like deep-sea chalky ooze; it has about the same consistency, is made up of the same nearly impalpable fine particles, and is of the same whitish color. A similar white marl deposit is also found, only on a most limited scale, in protected pools exposed to the very lightest wash of the sea in the recesses of the shore line.

The shores of the inner lagoons, and in many places the main shore of the island, is lined with mangroves, many of which are large, and form the most prominent landmarks available in the navigation off the west shore of Andros.

As far as Williams Island, about twenty-five miles to the northwest of Wide Opening, the bottom on the bank is composed of the same white marl. All the way to Billy Island we found no change in the character of the bottom, which seemed fully as barren of animal life as it proved while rowing to the shore of Wide Opening from our anchorage. On our way north from Wide Opening we steamed in water so shallow that we left in our wake a broad belt of white water, stirring up the white marl with the wash of the screw.

On going ashore at Billy Island we found it to consist of the same finely triturated æolian rocks. The shores were formed by miniature vertical cliffs of about eighteen inches in height, presenting all the appearances of water action so characteristic of the higher limestone cliffs on other islands of the Bahamas. The diminutive seas had eaten out small bays, formed promontories, and indented the coast in a manner no less characteristic than the shore lines of higher islands when exposed to the full action of the trades. Masses of dead shells are found blown up or thrown up on the diminutive beaches of the recesses cut out of the shore line. Billy and Williams Islands must at one time have formed a part of the northwestern extension of Andros. There is no part of the Bahama Bank which is so instructive as that now occupied by Andros. Nowhere else do we find so large an island undergoing all the processes of disintegration, division, and erosion which have on other parts of the bank ended in forming the submarine shoals, and leaving here and there traces of the former extension of the larger islands of which the bank was composed. Andros still occupies a comparatively large part of the Great Bahama Bank to the west of the Tongue of the Ocean; yet it is cut into three islands by the so called bights which connect the Tongue of the Ocean with the shallow waters of the bank to the westward of Andros. Its former southern extension is marked by the numerous small islands, isolated rocks, sand banks, and ridges reaching southward and eastward from the southern end of Andros. Its former western

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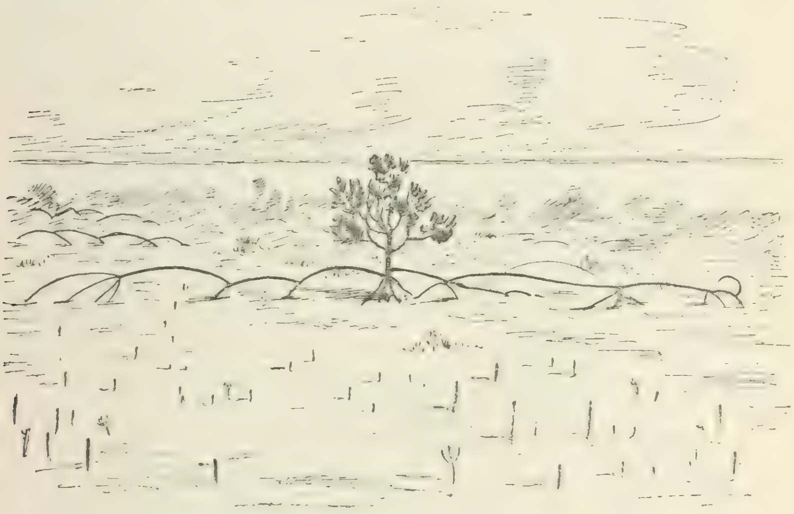
[1] See Northrop's description of the "Swash" ("The West Coast of Andros," Trans. N. Y. Acad. of Sci., Oct., 1890).



YOUNG MANGROVES, WIDE OPENING.

extension, perhaps close to the edge of the Santaren Channel, is well marked by the great belt of white marl, which we may see formed under our eyes on the shores of Wide Opening. The northern limit is marked by the spread westward and northward of the white marl, with here and there a remnant of the main island as an isolated cay, like Billy or Williams Island, reaching perhaps to the northern extremity of the bank, where the only traces of its former existence are the rocks, islets, and shallow bars extending from Great Isaac to Great Stirrup Cay, forming to the eastward of the northern extension of Andros a broad promontory, of which the Berry Islands and the Joulter Cays are the only remnants. On the west, along the line of the Old Bahama Channel, the Santaren Channel, and the Straits of Florida, we are reminded, by Lobos Cay, Guinchos Cay, and the disconnected flats and patches edging the channel as far as Orange Cay, of the western extension of Andros; while the Riding Rocks, Gun Cay, and the Bemini Islands, lying between Orange Cay and the Great Isaac, attest the former existence of the shore line of a large island — probably the west coast of Andros — along the eastern edge of the Gulf Stream.

The appearance of the east coast of Andros, the high æolian bluff of which flanks nearly the whole of the western edge of the Tongue of the Ocean, is in striking contrast to its low western shore. The east face of Andros is a series of alternating beaches and bluffs, extending from the northern extremity to High Point. The island is comparatively well wooded, large tracts being covered by pine and by hard-wood forests. To the south of Morgan's Bluff near the shore begins a magnificent coral reef, extending the whole length of the island, and running parallel with and distant from it half a mile to a mile and a quarter, with openings in the outer reef to allow the passage of spongers. This reef, though narrow, is one of the finest reefs I have seen, and the patches of corals and Gorgonians which flourish between the outer reef and the shore are not surpassed in beauty by the corals of any district known to me. These patches form an intricate network, rendering navigation inside the reef very difficult. In fact, it can be followed only by the eye. The inside patches of Gorgonians are in many places most luxuriant, while the outer reef is mainly made up of masses of Astræans and Madrepores; the patches between the outer reef and the shore consist of Porites, Mæandrinæ, and Millepores, growing upon the æolian rocks. These corals, when broken up by the action of the sea, supplied the sand forming the beaches which cover the underlying æolian rocks. I saw but few stretches of the shore coral rock formation.

The vegetation of Andros consists mainly, as I was informed by Mr. Chamberlain, of pine, mahogany, mastic, and the heavy undergrowths.

The ridge which runs parallel or nearly so to the coast is followed by a second ridge from forty to sixty feet high, separated from the first by a wide flat plateau, beyond which we come, by a rapid descent about five miles inland, upon the low flat land which extends to the western edge of the island and forms the marl shores we visited at Wide Opening.

Morgan's Bluff (Plate XXXIII.) has the finest limestone cliffs on the eastern face of the island. The outlying islands and rocks and islets off the east coast of Andros, of which High Cay is a good example, as far as the South Bight, are all of æolian origin, and have been separated from the main island by the same agencies which have been at work in other parts of the group. The æolian rocks of Andros itself differ in no way from those of other islands. The eastern edge of Andros is separated from the deep water of the Tongue of the Ocean only by the narrow shelf of the bank of which the eastern edge is occupied by the long barrier reef which protects the eastern edge of Andros, leaving an excellent well protected inside channel for small boats along the whole length of the island.

## From Andros to Orange Cay.

From Billy Island we steamed across the northern end of the great white marl belt forming the southern edge of an excellent sponging ground which extends northward towards the edge of the Bahama Bank, south of the Northwest Providence Channel. The white marl, as we stopped to dredge or to sound, seemed very barren of animal life. Here and there an occasional sponge could be seen. On our way to Orange Cay we found that the white marl as we got farther west gradually contained more coral sand, which became coarser and more abundant as we approached the western edge of the bank, where the bottom was again composed of the characteristic coral and æolian sand found upon other parts of the Bahama Bank. With the increase of the coral sand we came upon a species of Thalassia with huge roots, by which it anchored in the fine marl. The great development of the roots is very characteristic of the coralline algæ, which thrive upon the coral sand bottoms. A macroscopic examination of the marl from the shore of Billy Island showed that it contains a good deal of vegetable matter and a few Foraminifera, an indication most probably that the marl was formed in a lagoon with free access to the sea, perhaps a sink much like those on Nassau and on other islands, in the shape of salt ponds. The presence of Foraminifera in this marl, so like deep-sea ooze, yet known to be formed only by the slow trituration of æolian rocks in very shallow waters, raises the question of the depth at which Radiolarian earth, as at the Barbados and elsewhere (Baracoa), may have been formed. It is no more difficult to imagine that the formations round the shores of such a shallow water lagoon have been elevated, than it is to believe the same of an elevated coral reef. In the Billy Island marl the presence of Lobulina and Globigerina would merely indicate that the open sea had free access to the lagoon. Similarly, the Radiolaria of the Barbados earth may have floated into the shallow waters in which it was formed, were it not that the presence of Cystechinus, by analogy with our recent species, indicates deep water. The marl of the shore of Billy Island contained Lobulinæ and Globigerinæ, while the marl from nearer the edge of the bank, in about four to five fathoms, and within four miles south of Orange Cay, which contained a greater percentage of coarse coral sand, also contained Lobulinæ and Globigerinæ, as well as fragments of silicious Radiolarians. When within five miles from the edge of the bank the bottom was quite clear of mud and marl, and was composed mainly of nicely rounded particles of coral sand.

## From Orange Cay to Great Isaac.

**Plate I.; Plate XII. Fig. 2; Plates XXIV. to XXVI.**

When approaching the western edge of the bank off the Racolas Rocks to the south of Orange Cay, we began to see bars of corals in from five to six fathoms of water. This had now become much clearer, and, compared to the water on the midway of the bank, apparently carried nothing in suspension. Still farther to the westward could be distinctly seen the dark blue line indicating the deep water of the Gulf Stream off the edge of the bank. After passing the Racolas Rocks, we came upon Orange Cay, a low ridge of æolian rocks absolutely bare, pitted and honeycombed over its whole surface. Vessels crossing the banks from Stirrup Cay sail an almost straight course from there to Orange Cay, and next strike Salt Cay Bank, thus avoiding a great part of the strength of the Gulf Stream, and making for Havana from off Matanzas close to the north shore of Cuba. From Orange Cay as far as Riding Rocks bars of corals run parallel to the edge of the bank on an approximate north and south line. The corals on these bars are all flourishing, and consist mainly of heads of Astræans and of Mæandrinæ.

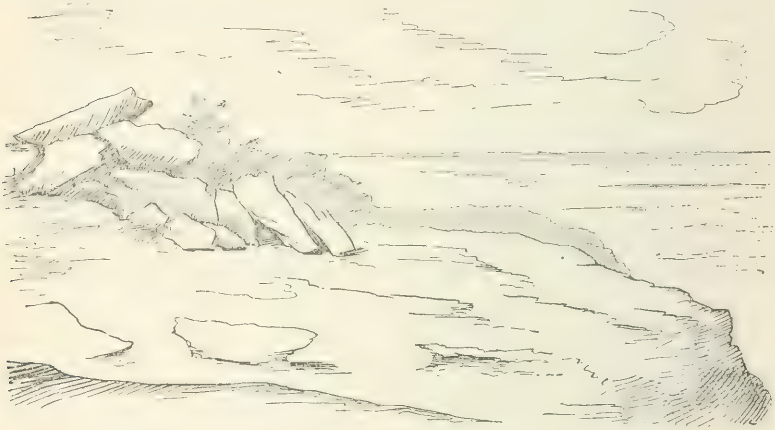
The shore lines of Orange Cay, as well as the adjoining isolated rocks, are all eaten away at the base, the surface being completely pitted and honeycombed; this small cay, with the scattered isolated rocks extending to Riding Rocks, being all that is left of the western part of the great Andros Island land. Riding Rocks are found, like Orange Cay, to be composed of the same kind of æolian rock. Masses of corals are flourishing, forming great patches more or less disconnected on the face of the bank towards the Gulf Stream, extending to fifteen or seventeen fathoms of water. Astræans, Mæandrinæ, Millepores, and Madrepores extend all the way to Gun Cay. Nowhere perhaps on the Bahamas is it more obvious that the existing bars of corals found along the sea face of the nearly continuous bank throughout the Bahamas have had nothing to do with the formation of the cays and rocks on the west side of the Andros Bank. The coral masses are merely surface growths as it were upon the banks, which owe their building up to entirely different causes and to a state of things which has long passed away.

From Riding Rocks to Gun Cay a series of isolated patches, rocks, and islets, all of the same character, sometimes in two or more parallel rows, run north on the edge of the bank; these are flanked on the westward by very flourishing patches of corals growing close together, and extending on the sea face of the bank into about seventeen fathoms of water. These rocks and islets are comparatively less barren as we go north. The remnants of the former land also increase in number as we approach Gun Cay, and become still more numerous and large with the Beminis and the adjacent rocks and islets. On the southern end of South Cat Cay there is a considerable æolian hill, covered with vegetation similar to that of other islands on the east face of the bank. North Cat Cay has a grove of cocoanut palms and low bushes. The sea face shore lines of this and South Cat Cay are protected against the action of the sea by lines of outlying rocks, and are thus less affected by the wearing action of the prevailing winds. South Cat Cay is high enough to have, near the middle of the north end, a line of low vertical cliffs, both the Cat Cays being somewhat higher than Gun Cay.

## Gun Cay.

**Plate XII. Fig. 2.**

On the south point of Gun Cay a lot of loose rocks are thrown up well above high-water mark. The cliffs of the southern shore are eaten away, and on the western face of the cay the rocks up to the line of scanty vegetation are deeply pitted and honeycombed. All along the west face of Gun Cay rectangular masses of rocks are thrown up close to the line of vegetation. These masses of rocks are the fragments of the shores torn off from the vertical cliffs by undermining, and then thrown up by the action of the heavy seas or hurricanes. Picket Rocks derive their name from such a mass of angular rocks thrown up on the very crest of the ridge of the cay, looking a little way off like an irregular picket fence. Holm Cay is another island of similar character, but smaller.

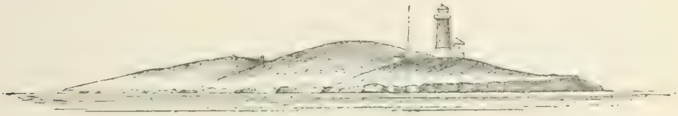


ÆOLIAN ROCKS THROWN UP ABOVE HIGH-WATER MARK, GUN CAY.

Running parallel with the line of outer rocks which make the extension of Gun Cay to the north, we crossed magnificent banks and patches of corals, some of which run close up to Gun Cay, as well as to the rocks in the vicinity. Off the little sandy reach inside of the north end of Gun Cay we brought up large masses of Thalassia in the dredge.

On the east face of Gun Cay the shore rocks are so eaten away as to form numerous caverns and cavities in the face of the shore line.

Going on shore, we found it composed of the ordinary æolian rock of the Bahamas, its character admirably shown in the cuts made for the boat landing and for the foundation of the derrick used in handling the supplies. The cay, wherever exposed to the strong waves of the Gulf Stream, is deeply pitted and honeycombed. We found a few specimens of the same pupa so common on other islands of the group. The vegetation was very scanty, — a few scattered specimens of cactus, wild grape, wild geraniums, and verbena, — with the usual plants characteristic of the shore belt throughout the Bahamas. Among the most prominent rocks north of Gun Cay, between it and the Beminis, are Turtle Rocks, forming a low rocky æolian ridge.



GUN CAY.

## The Beminis.

**Plate XII. Fig. 2.**

The Gulf Stream skirts close to the western edge of the two Beminis. They are separated by a picturesque opening, forming an excellent harbor even for boats of a considerable size. At the south end of both South and North Bemini we find a long line of angular æolian rocks thrown up by hurricanes well above high-water mark, often fully twenty feet. From here to the northern end extends a long coral sand beach, disconnected in many places by extensive patches of shore built coral rocks, covering in many places the underlying æolian formation. The greater part of the shores of the Beminis is made up of this shore deposit, piled up above the older æolian rocks wherever they have been washed away, and forming small cliffs along the northern face of the western shore line of North Bemini. Here and there an occasional cliff of the older æolian is seen, but greatly weathered and worn, as near the northern extremity of North Bemini, some distance above the village. The sea has thrown up a high beach and formed a lagoon at that end, which is filled with mangroves and small mangrove islands. The outlying rocks of North Bemini are all æolian, the surface pitted and honeycombed, and eaten away at the base. On the gulf side of the Beminis, and all the way north to Great Isaac, we meet fine patches of corals in from four to six fathoms of water. These patches and bars extend but little way eastward on the bank, and flourish most luxuriantly as we approach the Gulf Stream edge of the bank out to fifteen or sixteen fathoms, where they often cover extensive tracts separated by irregular sandy lanes.

## Great Isaac.

### Plates XXIV. to XXVI.

Great Isaac, as it is approached from the south (Plate XXV.), reminds one of Double Headed Shot Cay, with its rounded outline and outlying islets and rocks presenting a most barren and desolate appearance. The southern faces of the island, and of its adjoining islets and rocks, are all cut off by low vertical cliffs, full of caverns and cavities. The surface of Great Isaac is an admirable example, perhaps one of the best, of the forces which have been at work during the subsidence of the Bahamas. The æolian structure of the rocks is everywhere most apparent. The action of the sea in undermining the shore slopes and forming low vertical cliffs by the breaking off and falling into the sea of huge angular masses of rocks is seen on all sides. The action of the sea during hurricanes in throwing up huge masses far above high-water mark is not better shown on any other island of the group. Finally, the action of the salt-water spray and waves, as well as of the tropical rains, in pitting and honeycombing the surface of the island, the former near the shores, the latter everywhere else over the cay, cannot fail to strike the eye of the most casual observer. As we passed the west end of Great Isaac we observed a number of huge isolated irregular rocks, left far above the high-water mark, passing into an irregular mass of angular blocks forming a rude broad wall, left as a witness of the fury of the hurricane of 1876. But on the north face of the island we come upon another tract covered by still larger blocks, thrown up by an older hurricane, the date of which is not known. Two of the largest of these blocks we measured, and found them to be, the one twelve feet eight inches long by four feet wide and six feet high, at a distance of one hundred and twenty-five feet from the shore and fully twenty-five feet above high-water mark; the other was fifteen feet six inches long eleven feet wide and six feet high, at least eighty feet from the shore and about eighteen feet above high-water mark (Plate XXIV.). On the highest part of the island, to the eastward of the lighthouse, we found a number of fantastic isolated pinnacles of æolian rock left standing high above the present general level of the cay by the denuding action of the tropical rains. Many of these pinnacles were limestone tables of varying tops and heights, with a slender pedestal still attached to the ground. They owe their origin undoubtedly to the harder character of the surface limestone at certain points.

On the north side the slope of the island is very gentle. There are many pot-holes and sinks, as well as ocean-holes, on the northern face of the cay, and at the south side the sea has washed the cliffs into the most fantastic pinnacles (Plate XXVI.), some of them several feet in height, so that a part of this shore recalls very vividly the aspect of the surface of Eleuthera near the Glass Window. Only the most scanty vegetation is found at certain points of the island, not enough for the food of a goat. A cactus, a few stunted bushes and shore plants, compose the flora of this island. Gun Cay, the Beminis, Great Isaac, and the long line of rocks and sand bars to the eastward of it extending to the Berry Islands, such as North Rock, the East and West Brothers, and the Eastern Isaacs, are probably the remnants of the northern and western edges of a larger island, now only barely apparent above the level of the sea, perhaps itself formerly a part of Andros. Off Little Isaac the bottom samples became quite coarse, consisting principally of broken shells and masses of coralline algæ. When approaching Great Stirrup Cay, about thirty miles southeast of Great Isaac, the bottom was coral sand, with many broken shells, small whitish Mellita hexapora, and light brownish Clypeaster. In fact, the prevailing tone of the whole fauna of the banks proper is of light hue, except where coral patches are found close to the edge of the bank, and nothing is more apparent than the bleached aspect of the shells, echini, or coralline algæ characteristic of the bank itself. The darker patches of sponges, corals, and Gorgonians alone apparently form an exception to the general monotony of color characteristic of the bottom on the inner parts of the banks.

## From Great Isaac to the Berry Islands.

**Plate I.; Plate XII. Fig. 4.**

To the eastward of Great Isaac run a series of rocky ledges, the remnants of former cays, running parallel with the trend of the 100 fathom line, distant from it three to seven miles, known as the Northeast Rock, the Brothers, Little, Middle, and East Isaacs, Rockawash, and other rocky banks, ending with the Gingerbread Ground in the east. There we strike the extensive bight between it and Little Stirrup Cay, where the bank slopes most gradually from the 3 fathom line to the 12 or 15 fathom line, and then drops suddenly to the 100 fathom line, the ledges named above forming the northwestern edge of the bank.

## The Berry Islands.

### Plate XII, Fig. 4.

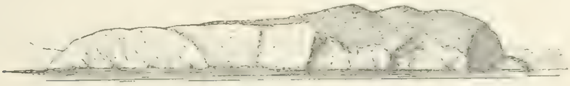
We passed the islands to the westward of Great Stirrup Cay in the dark, but that island and those of the Berry Islands which we saw during the day were all of æolian rock. Great Stirrup Cay is full of potholes and sinks; it is comparatively well wooded, as well as many of the Berry Islands and of the islands to the northwest visible from our anchorage in Great Harbor.

All the way from Great Harbor south we found irregular patches and bars of corals on the shelf to the eastward of the Berry Islands, extending from three to four fathoms or less to fifteen or sixteen near the eastern edge of the bank. Coming from the west, I am informed that from Gingerbread Ground similar coral reefs extend as far as Great Harbor Cay, on the shelf of the banks, outside of the cays.

The islands, islets, and rocks known as the Berry Islands, extending along the Providence Channel and forming the northeastern edge of that part of the bank of which Andros is the principal land, are both as to number and size in marked contrast with the small and insignificant islets and rocks which occupy the edge of the bank flanked by the Gulf Stream. The principal cays of the Berry Islands, such as Haines Cay, Little Harbor Cay, Alder Cay, Bond's Cay, as far as Whale Cay, present no features of special interest. Their surface appears well pitted and honeycombed, as their eastern face gets the full force of the northeast trades. Near their highest point they are covered by a very scanty vegetation. The outer line of cays protect a beautiful sheet of water of a brilliant light green.

They show the usual variation in height of from twenty-five to thirty feet, occasionally rising, as at Haines Bluff and Devil's Bluff, to fifty or sixty feet, their eastern faces presenting the ordinary variation of low vertical cliffs where the headlands have been cut off by the action of the sea, or the more or less extended coral sand beaches stretching between those promontories, with here and there extensive walls of æolian blocks thrown up above high-water mark, as on the Market Fish

Cays. The cays in this vicinity are more exposed to the action of the sea, the eastern shelf of the bank being quite narrow, and in many cases the eastern faces are formed by low vertical cliffs of æolian rocks, thirty to forty feet high, separated by short stretches of sand beaches. The north end of Bond's Cay and the sea face of Alder Cay are both very much eaten by caverns, with rows and patches of loose angular blocks thrown up above high-water mark. There is but little vegetation on either Cay. Beaches and low cliffs alternate along the southern end of Bond's Cay. Along the whole length of the north end of Whale Cay the action of the sea is well marked in the undermining of the low cliffs forming the sea face of the cay.



DEVIL'S BLUFF.

The effect of the shallow wide shore shelf to the east of the Berry Islands is very marked on the swell, which is far less powerful than on the Atlantic or Gulf face of the bank, wherever deep water comes close to the sea face of the cays.

An extensive tract of sand bores, dry at low water, runs from the Northwest Channel to Great Harbor Cay. In the whole of the track to the eastward of them as far as the Berry Islands there is only a very limited area with a depth of one fathom. To the westward of the cays from Great Harbor Cay to Whale Cay the shores run into broad sand flats. The westward extension of these sand flats forms the southern edge of the bank from Whale Cay and the Chub Cays to the entrance of the Northwest Channel and to the Joulter Cays. From that edge of the bank extensive sand bores run diagonally across in the direction of Haines Cay. (Hydrographic Chart, No. 26$^a$.)

Fine patches and bars of corals follow us south, with lanes of sand separating them and extending to the edge of the bank from three or four fathoms into fifteen or sixteen. Toward the outer edge the corals grow most vigorously. The same kind of bottom followed us as far as Whale Cay. Corals begin to grow in from three to four fathoms, where they are less disturbed by the constant movement of the coarse coral sand of the bank, and hence the corals have not assisted in building up the shores. Very few coral patches come close to the surface, as they do in the Florida Cays, where the corals play an important part in the formation of the outer ones.

From Whale Cay we crossed over to Mastic Point on Andros. As soon as we got into deep water after leaving the bank we began to encounter again flying fishes, not one of which we had seen while steaming on the outer shallow part of the bank.

## THE LITTLE BAHAMA BANK.

**Plate I.; Plate X. Fig. 1.**

The Little Bahama Bank is dumbbell-shaped, one of its shanks running in a northwesterly direction, the other irregularly north and south. The northern edge of the bank from Walker Cay Channel to Elbow Cay, and the eastern edge from that point to Cheroki Sound, is skirted by numerous cays running nearly parallel with the 100 fathom line, at a distance varying from one to four miles. The rest of the southeastern edge of the bank is flanked by the high cliffs of Great Abaco as far as Hole in the Wall; from that point the shore trends to the southwest, and extends northwest from Southwest Point to Rocky Point. Of the outer line of eastern cays the principal ones are Walker Cay, the Double Breasted Cays, Stranger, Carter, Fish, Pensacola, Spanish, Munjack, Green Turtle, Great Guana, Man-of-War, Elbow, Tilloo, and Lynyard Cays. A broken line of reef extends from Cheroki Sound along the eastern edge of the bank to Matanilla Reef. This reef becomes specially prominent north of Elbow Cay, leaving only here and there a passage through the reef for small boats to gain admittance into the large sheet of water, from two to six miles wide, and twelve feet deep, which separates the outer cays from the eastern shores of Great and Little Abaco. Large craft can enter this inner sheet of water through Man-of-War or Whale Channel Cay.

As far as we saw the outer line of cays from the Stranger Cays to Lynyard Cay, they are all low, generally bare, Green Turtle Cay being an exception. They probably represent the outer line of æolian rock hills which once formed the eastern shore of Great Abaco, but which, owing to the subsidence and to the wearing action of the sea, has separated these hills into numerous islets and formed the wide and navigable channel intervening between them and Great and Little Abaco.

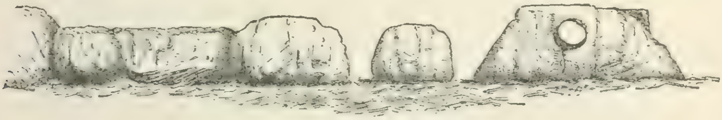
In the vicinity of Little Harbor the outer range of æolian hills is still connected with the main island, Ocean Hill and the adjoining promontories forming the southern edge of the harbor and the northern boundary of Cheroki Sound, while the promontory of Sweeting protects the northern side of Little Harbor. At Marsh Harbor settlement and at Black Point, both on Great Abaco, promontories nearly two miles in length are left as monuments of the former eastern extensions and connections of Abaco with the outer cays. In fact, very little more wearing away would separate the promontories forming Little Harbor from Abaco, and turn them into cays similar to the outer line, leaving perhaps at the same time a second inner row of cays like those now in formation off so many parts of the eastern shore of Abaco, traces of which farther north are seen in the numerous banks of all sizes and shapes which exist both to the westward and to the eastward of the outer cays, being parallel to them in a general way.

## Great Abaco Island.

**Plate X. Fig. 1; Plate XL.**

We made the lighthouse on Abaco Island at Hole in the Wall, the southern extremity of the Little Bahama Bank. That part of Abaco is low, with rounded outlines (Plate XL.). The rocky surface is bare, all that part of the island being exposed to the full action of the prevailing trade winds and swell. In consequence the shore is formed of low cliffs, having the peculiar basaltic appearance so characteristic of the darker limestone cliffs of the Bahamas. The surface of the island within reach of the action of the sea is pitted, honeycombed, and full of pot-holes. This is specially seen on the east face of the Lighthouse Hill and the spit to the south of it.

A well marked narrow rocky promontory, covered near the shore by pinnacles, runs out from the southern end of the island, at the extremity of which are situated two islets undermined at the base. Near the extremity of this narrow promontory the sea has broken through and formed a large hole, which has given to the locality its name of Hole in the Wall. The outlying islands have perhaps been formed in part by



HOLE IN THE WALL.

the same process which will in time separate the extremity of the promontory as a distinct islet, now connected with the inner part of it only by a comparatively thin arch. From its exposed position we naturally find many fragments of rock thrown up on the shore. A few at the base of the cliff leading to the lighthouse are quite large. The largest rock train is thrown up on the beach near the spit to the west of Abaco Lighthouse. The cliffs to the westward, to the eastward of Southwest Spit, are the remnants of a range of æolian hills existing at one time to the south of those which form the extension of Lighthouse Hill. These western hills must have reached very close to the edge of the bank before the general subsidence of the Bahamas had produced any marked change in the topography of the land. The valley which separated them from the northern range of hills is still well marked.

After turning the Southwest Spit we ran parallel to a long coral sand beach, the shore line of which was flanked at intervals by stretches of angular rocks thrown up by southeastern hurricanes or gales above high-water mark and extending inland. On landing we found rocks, sponges, Gorgonians, and large masses of corals, thrown up to a considerable distance on the lowland, forming an extensive plateau extending inland behind the beach. Soon after passing Southwest Spit we began to see fine stretches of pines, which are so characteristic a growth on the larger islands of the Little Bahamas.

The edge of the narrow bank flanking western Abaco is covered with fine coral heads, growing abundantly in from three to ten fathoms close towards the shore, and separated by wide lanes or patches of sand. On the western face of the Little Bahama Bank this edging of corals is nearly continuous, extending all the way from Southwest Spit on Abaco to Memory Rock, where we entered on the bank to cross it *en route* for Green Turtle Cay.

Great Abaco from Southwest Spit westward is low, and covered with a fine forest of pines, which extends into the interior. The Lighthouse Hill range gradually falls to the westward, but extends to the northeast of the lighthouse, and forms the eastern face of the island, which is edged by vertical cliffs from forty to one hundred and fifty feet in height, forming a nearly continuous wall, upon which pounds the heavy trade swell. These vertical cliffs extend north as far as Guineaman's Bay, where the outer row of rocks, islets, and cays begins, extending in a nearly unbroken breakwater off the main island from Cheroki Sound as far as Matanilla Reef. On the west side the lowland extends as far as Rocky Point, and then disappears to form the extensive shallow bank which stretches to the southeastern extremity of Bahama Island on one side, and to Little Abaco on the other. On the interior of the bank the west face of Great Abaco runs at many points close to the eastern shore of the island, leaving only low, narrow ridges connecting the various parts of this singular island (Plate X. Fig. 1). On examining the chart, one cannot fail to be struck with the endless islets and passages which have been left on the east coast of Abaco as records of the subsidence of the bank, and the numerous cays which flank the western edge of the bank between Rocky Point and the southeastern end of Bahama Island, while the many cays found upon the shallow interior bank attest the former extension of the Abaco Bahama Island Land. The Little Bahamas are perhaps a finer example than even Andros can be of the former greater extension of the land, and of the causes which have resulted in the present configuration of the group.

The Abaco Bahama Island Land, which once covered the greater part of the Little Bahama Bank, and probably corresponded in outline approximately with the line of ten fathoms, was exposed at its northwestern face to the violent action of the northers. They have eaten away the whole of the northern face of Bahama Island, leaving only Memory Rock and the banks to the north as witnesses of its former extension. On the north face of the Little Bahama Bank the patches forming Middle Shoal, Matanilla Reef, and the long line of outer cays, give us approximately the outline of the former Little Bahama Land, of which Little Abaco and the cays extending to the westward to the Centre of the World are remnants, these remnants being in turn the outliers of Great Abaco before it became disintegrated by the action of the northers, when it was perhaps only separated by a narrow channel from Bahama Island. Of course, as soon as a wide channel was formed to the north of Bahama Island or to the westward of Abaco, the action of the northeast trades also came into play to cut away the low shores of these islands, thus helping to increase rapidly the dimensions of the bank.

But what has made the shape of the banks such as they are, and what has shaped the outline of the old land in so absolute conformity to what we may reasonably assume to have been their original outline?

As far as the shape of the Windward Islands is concerned, we can still see the action of the volcanic forces which have elevated islands of very different shapes and different sizes above the bottom of the surrounding ocean, — islands which are separated one from the other by channels of very varying depths, and round which have been formed on one face or the other narrow fringes of limestone by the reefs surrounding them. As we pass northwards from South America we find that these islands become larger, or rather that they are the summits of larger plateaus, forming banks of greater or less extent and separated by channels of various depths. We also see that on some of the banks there are no volcanic islands, the whole surface of the plateau being covered by coral sand, in part the remnants of limestone tracts which had a greater extension, or in part perhaps of limestone banks which during periods of great volcanic activity have gradually formed upon the folds of the bottom of the ocean. Even granting for the Bahamas the greatest possible subsidence as indicated by the deepest ocean-holes, the outlines of the banks at the time of their greatest elevation could hardly have been materially different from that of the present charts, as the whole change of level is taken to be well inside the 100 fathom line, at not more than fifty to sixty fathoms. Take the sea face slope as we find it to-day, it would not have changed materially the position of the coral reefs which must have been growing there, perhaps as barrier reefs exposed to the disintegrating action of the sea, and supplying by their own disintegration the material needed for the formation of the æolian hills from which the Bahama Land was built. Or, more probably, these reefs existed as fringing reefs, much as they do in our days along some parts of the coast of the Sandwich Islands, and from them were formed the immense stretches of coral sand beaches which, swept alternately by the trades and the winds prevailing at other seasons, supplied the sand to build up the gigantic dunes of former days. These formed the highest hills of the Bahamas, and they in their turn have, from various causes mentioned in this account of the Bahamas, been reduced to their present limits.

## The Bank from Great Abaco to Bahama Island.

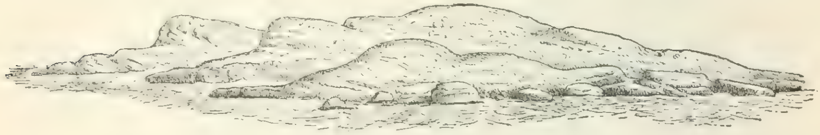
**Plate X. Fig. 1.**

Between Rocky Point (Great Abaco) and the southeastern extremity of Bahama Island only a few cays exist, — Gorda, Channel Cay, Black Rock, Lily, and Burrow Cays. The reef can be crossed at Burrow Cay and at Mores Island Channel. Between Burrow Cay and Bahama Island we found numerous sand bores extending five or six miles from the edge of the bank. Inside of Gorda Cay and to the east of Southern Cay and of Mores Island extends a great tract filled with banks and numerous sand ridges reaching towards the ill defined low swampy shores of the western side of Great Abaco. These sand bores also extend in a northerly direction from Mores Island to the sand bores east of Burrow Cay. In crossing the bank from Mores Island to the Woollendean Cays, we carried from one and a half to two fathoms of water, and before reaching the cays had struck the territory of the so called marl of the Little Bahamas. It seems to have been formed under very much the same conditions as those which have formed the great white marl flats to the west of Andros; but the Woollendean Cays and the Joe Downer Cays being the remnant of a land rather higher than that on the west shore of Andros, this marl is not so pure, and contains a greater amount of vegetable matter derived from the decomposition of a larger amount of soil.

When off Rocky Point we could easily follow with the eye the changes which had perhaps taken place in the configuration of the west side of Abaco. To the east stretched the low coast of the island itself, covered with a dense forest of pines, and deeply indented by channels which seemed, as seen from the rigging, to cut the shore line into numerous islets. To the westward extends a low rocky spit, and still farther west rocky cays are found on the edge of the bank, — the outliers of the former Abaco. Gorda Cay, the summit of which is covered by a regular picket line of angular æolian rocks, attests the strength of the hurricanes which have gradually eaten away the greater part of the west shore of Abaco; while farther inland Mores Island and the Woollendean Cays, æolian islands rising upon the shallow interior bank, indicate the action which has gradually reduced the western part of Great Abaco to its present dimensions. Long Cay Rocks and other small cays south of Mores Island are bare, like Gorda Cay, though often topped here and there like the latter by a wall of loose rocks thrown up during the hurricane season. There is excellent sponging on the interior of the bank. The bank is entered by a good passage a little north of Mores Island, and in that way the west coast of Great Abaco can be reached. We anchored in Rock Harbor, on the west coast of Abaco, after having visited the Woollendean Islands and the marl district of the Little Bahamas.

Burrow Cay is low, not more than twenty feet in height, with vertical cliffs on the channel side. A long row of angular æolian blocks is thrown up on the western face of the island to a height of about fifteen feet above high-water mark. On the western extremity a small low rocky cay protects the northern shore of the island from the action of the northers. On the northern shore there is a short stretch of recent shore coral rock, masses of Nullipores, of Gorgonians, of corals, and an immense accumulation of large conch shells covering an extensive flat, and also forming a wall of at least five feet in height above low-water mark. These conchs are of course of all sizes, and the fragments into which they have been broken are in all stages of wearing by the action of the sea. Such masses of conchs, forming almost as great an accumulation as might be due to an Indian shell heap, we have not found anywhere else in the Bahamas, although in many places we met with smaller heaps. All along the line of the bank, in from four to six fathoms of water, we found the continuation of the coral reef which we struck soon after reaching the lighthouse near Hole in the Wall.

Owing to threatening indications of a norther, we turned back, and passing in by Channel Cay entered on the Little Bahama Bank. We soon came upon the northern extremity of Mores Island, which can readily be distinguished by the greater height of the cay and the rounded hills of which it is formed. In this vicinity the bank is thickly covered with conchs, which are collected by the inhabitants and burned to make lime. Mores Island is composed of æolian rock, and is fairly wooded. Here and there the promontories of some of the hills have been washed away by the sea, so that the shore is composed of patches of low limestone cliffs alternating with sandy beaches. On the west shore the modern coral sand beach formation hides from view the underlying æolian rock. From Mores Island towards the north end of Abaco there is excellent sponging ground, and all the way from Black Rock to Mores Island the bank is covered with extensive patches of sponges and Gorgonians. The extensive coral reef to the westward of Black Rock and Channel Cay reaches some little way over the bank, and shows special vigor in the vicinity of the Channel.



MORES ISLAND.

Off the northeast point of Mores Island the dredge came up filled with several species of coralline algæ and sponges. The bottom samples contained but few specimens of Foraminifera, and the sand at this point was already much finer and more sticky, as compared with the coarse coral sand of the entrance of the Channel. We found an abundant surface fauna off Burrow Cay, — Leptocephalus, Squillæ, pelagic flounders, Sagittæ, Doliolum, Diphyes, Copepods, floating algæ, and many larvæ of Crustaceans. After we passed Mores Island the specimens of the bottom became more and more sticky, and contained a greater number of Foraminifera, changing also to a grayish color. As seen from the northwest, the northern extremity of Mores Island, with its rounded hill-tops, is very characteristic, and in striking contrast to the low æolian hills which form the southern part of the island. On the horizon to the south is seen the low line of Great Abaco, covered with its pine forests, and to the eastward the line of the two Woollendean Cays, the outliers of the former extension of Great Abaco to the west of the marls. These cays are partly rocky and partly sandy. The sea, although shallow, has evidently considerable force here, especially during the northers, and low walls of æolian rocks are thrown up here and there on these cays just at high-water mark. We landed on one of the cays to the north of Cambridge Harbor. It consisted of æolian rocks in an interesting stage of decomposition, nearly marl, the holes of the rocks full of red earth and of vegetable matter. The sand on the beaches was made up of the same material, a little less compact and quite marly. This stage of the æolian rock seemed to be the condition immediately preceding that of the locality which is marked "The Marls" on the charts extending from the Woollendean Cays to the eastward towards Abaco and to the northward to Little Abaco. The so called marl which we obtained just inside of the cays differed greatly in its darker color from the whitish marl west of Andros. It also differed materially in being made up of far coarser materials, though it seemed to be fully as tough and sticky as the white marl from Andros.

As we approached the northern extremity of Great Abaco, near Norman's Castle, we could see the æolian cliffs on the south of it, formed from the hill slopes cut away at the base. At many points huge blocks, eaten away at their base, had been broken off, and looked now like huge white sails scattered along the coast line. It is interesting to follow to the westward of Norman's Castle the continuation of the æolian hills, which as small cays extend in a line outside of the main shore of Abaco and form Rock Harbor, the lowland lying between them and the mainland having all been washed away. The rocks were, as at Woollendean Cays, nearly changed into marl, mixed with more or less vegetable matter and red earth, so that very little additional disintegration would change it into the sticky and half sandy bottom so characteristic of this part of the Little Bahama Bank.

The chain of small cays in the vicinity of Rock Harbor, to the westward of Great Abaco, affords one of the best examples of the evidence we have of the former continuity of the many cays scattered all over that part of the bank. The cliffs of the cays are eaten away at the base by the slow action of the sea, which here has a far more limited range than when acting upon the Woollendean Cays to the southward. The bottom here is sticky, and, though still of the characteristic gray color, is made up of much finer particles than the samples of bottom we obtained on our way to this point from Mores Island.

The few large pines still left upon some of the smaller islands near Rock Harbor indicate clearly their former connection with the pine forests which are seen upon the main island (Great Abaco) to the eastward. Rock Harbor Cay was interesting as showing us the remnants of the inner western line of hills which form the Black Point of Little Abaco, appear again on Randall's Cay and on Norman's Castle on Great Abaco, and which may have formed the line of hills connecting Great and Little Abaco.

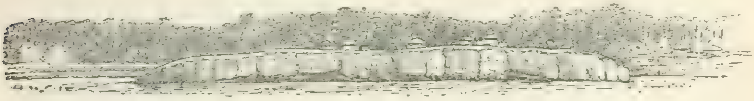
Little Abaco is separated by a narrow shallow channel from Great Abaco, and is only a narrow spit, the remnant of a line of hills running westward from the northern extremity of Great Abaco.

Coming back to Channel Cay, we pushed rapidly north to Bahama Island, steaming all the way from Channel Cay over the fine coral reef which fringes the western edge of the bank in from four to ten fathoms. The reef is bare at many points, especially in the extension of some of the ledges of rocks or low cays in the channels formed between them. The western slope of the bank is often very steep; it was not an uncommon occurrence while steaming over the reef to see the patches of the great coral heads in from five to eight fathoms on one side of the yacht, while on the port side we could not see bottom. From Burrow Cay to Carrion Crow Harbor there is a continuous stretch of coral sand banks separated by shallow channels, leaving passages for small boats to enter the bank. In the channels, or flanking these sand banks or their extensions as rocky ledges, thriving patches of large heads of corals could be seen whenever we came near enough to the outer line of cays. A few miles north of Carrion Crow Harbor the line of the great barrier reef, which runs parallel with Bahama Island, makes a sharp angle. As we ran parallel with this beautiful reef, we could follow the spurs of the main reef striking toward the shore of the island, and becoming changed at many places for a short distance into a fringing reef.

## From Bahama Island to Memory Rock.

**Plate X. Fig. 1; Plate XXXIX.**

Bahama Island forms the southern face of the northwestern shank of the Little Bahama Bank. It is sixty-five miles in length, but not more than six to seven miles in width. It is low, covered with a thick forest of pine. It may be fifty to sixty feet at its highest point, to the east of High Rock. The high ridge runs close to the south shore, and on crossing this we come upon the level stretch sloping gently north to the northern shore. Its southeastern extremity is broken into numerous low cays, and the north shore, which has not been surveyed, appears, as far as could be seen from the rigging, to be made up of innumerable low wooded (pine) cays running east of Settlement Point.



HIGH ROCK, BAHAMA ISLAND.

The highest cliffs we saw were at High Rock, where there is a small settlement, but even there the cliffs are not more than from twelve to twenty feet. In the vicinity of High Rock, to the eastward of Gold Rock, where we anchored, we had an excellent opportunity to see the barrier reef growing upon the submarine extension of the shore æolian rocks. The reef where we anchored is in about four fathoms of water. We dropped our anchor in an open space between patches of fine heads of Porites, of magnificent huge clusters of Madrepora palmata and colossal heads of Mæandrinæ and Astræans, many of them overgrown by splendid Millepores. Inside the reef, towards the shore, the sheltered waters were filled with patches of large Gorgonians and isolated coral heads. The distance from the 5 fathom line to the shore line is nearly a mile. Inside of this the coral heads were not very numerous, except in the lines where they formed spurs reaching to the shore of Bahama Island, constituting an incipient fringing reef. The shore æolian rocks are well protected, except at such places as High Rock, by the barrier reef running parallel with the shore line of the island. Back of the beach the highest point cannot be more than ten to twelve feet. The surface of the exposed rocks is more or less water-worn from the combined action of the rain and sea. Behind the shore line of rocks extend vast flats, the pine barrens of the island. The æolian rocks are everywhere fully exposed, presenting the peculiar characteristics of the great expanses of level or nearly level surfaces which in other islands frequently separate parallel ranges of æolian hills. In the sinks and pot-holes, or depressions of greater dimensions, pools and ponds, often of considerable size, have accumulated, many of which are separated from the sea only by the narrow wall forming the low line of æolian hills immediately back of the shore.

The shores of Bahama Island, all the way from Carrion Crow Harbor to our anchorage at Turtle Reef near High Rock, have once been a succession of coral sand beaches and of low cliffs along the edge of the low line of hills, forming a sort of dam between the pine tract levels and the edge of the island. Beyond Turtle Reef the extension of this line of hills forms a few insignificant cays to the west of Gold Rock. The reef is outside of this line of cays, which represents a part of the ancient shore line of Bahama Island. The reef dies out at Southwest Point, where the shore is clear close up to the beach. Beyond Southwest Point, at Barnard's Point, the low shore hills with vertical cliffs are again characteristic of the shore line, the pine barren plains appearing to be from one half to three quarters of a mile behind the beach mound. Wherever there is any outcropping of rocks between the stretches of coral sand beaches, many blocks of æolian rock are thrown up above high-water mark. There are a number of these rocky outcrops, and as we go north past Southwest Point the sandy beaches become shorter and are much more frequently interrupted by considerable lengths of outcrops. Hawk's Bill Creek is an estuary which has cut Bahama Island in two, and which comes out on the north side. The shore line of cliffs leaves a wide opening flanked with mangroves and shrubs; in the distance are the pine barrens about one mile inland. Soon after leaving Hawk's Bill Creek the pine barrens recede farther from the shore, and towards the narrower part of the northern extremity of the island the pines diminish gradually in size and in thickness, becoming quite scattered. The low range of shore hills increases in width, extending farther inland. The continuation of the northern extremity of the island consists of four or five small cays, the remains of the former northern extension of Bahama Island. These small cays are of the usual type; the rocks are æolian, with vertical faces more or less undermined, and the surface of the islets pitted and honeycombed. As the pines diminish north of Hawk's Bill Creek, their place is taken by scrub vegetation. The island becomes quite flat; there are but few rock exposures, and longer reaches of sand beaches. We still find flourishing patches of coral heads all along the coast, but they are disconnected, and the patches are often far apart. When off the northern extremity of Bahama Island we could see from the rigging the east shore of the island cut up into numerous small islands, many of which are still well covered with pines, far better than is the western part of the northern extremity of the island. These numerous cays and estuaries are not marked on the charts; in fact, the eastern and northern coasts of Bahama Island have not as yet been thoroughly examined and mapped out. Here and there on the west coast, close to the shore, are left a few pine trees, and the mangroves are in many places large and most flourishing.

All along Bahama Island, as well as along Andros, where the barrier reefs are perhaps better developed than elsewhere along the sea face of the bank, wherever there are breaks in the barrier reef so that the shore line is not protected by it from the action of the sea, we find stretches of sand beaches corresponding to the openings left in the barrier reef; while opposite the unbroken reaches of the barrier reef the shores are rocky, exposing in full view the underlying æolian rocks, which are not covered up in part by the reef sand, as in the shore opposite the breaks.

After leaving Settlement Point we came upon Indian and Wood Cays, the rocky remnants of the western side of Bahama Island. Sandy Cay is low, not more than fourteen feet in height, with no exposed trace of the underlying æolian rock of the bank.

Memory Rock (Plate XXXIX.), close to which we passed as we turned eastward to cross the bank, is perhaps one of the most characteristic of the outlying sentinels of what once formed a part of the greater Little Bahama Land. The gradual disappearance of this land as we pass north is most characteristic. We can as it were follow the disintegration which has taken place about the northern part of Bahama Island, the character of which changes radically as we leave the pine barren flats and pass to the bare rounded rocky hills, pitted, honeycombed, and worn, which form its western end, and to the numerous cays extending eastward, thickly wooded, covered with pines, which are the continuation northward of the pine barrens of the main island.

Nearer the western edge of the bank, Indian and Wood Cays are more or less exposed to the same agencies which have acted upon the Bahama Islands in so uniform a manner. On Wood Cay we find large blocks of æolian rock thrown up above high-water mark, and above this belt it is covered with low shrubs. When we finally come to Memory Rock, we find nothing but a few pinnacles of æolian rocks, pitted and honeycombed, and worn into fantastic shapes, the only land still visible of the northern part of the older Bahama Abaco Land.

The northwestern extremity of the bank is fringed by patches of coral reefs and sand bars. The reef which extends nearly unbroken from Southwest Point on Great Abaco along the western face of the Little Bahama Bank beyond Memory Rock runs to within about fifteen miles from Matanilla Shoal, the northernmost coral patch on the bank.

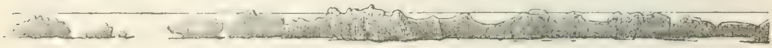
## From Memory Rock to Green Turtle Cay.

**Plate X. Fig. 1; Plate XXI.**

The character of the bottom on the bank from Memory Rock for about thirty miles eastward is that of grayish coral sand, rather finer than the bottom samples near the edge of the bank, which are clear coral sand and broken shells. At each haul of the dredge masses of Thalassia were brought up.

The Barracouta Rocks, five to six isolated little rocky patches, twelve to fourteen feet high, are pitted and honeycombed, and water-worn at the base. The æolian lamination in some places is most distinct, dipping at times thirty-five to forty degrees. The cavities of these rocks were in part filled by very peculiar rounded lumps of a cellular mass of red earth, sometimes also arranged in ridges on the dividing edges of adjoining depressions.

Little Sale Cay rises about twenty feet above high-water mark, and is devoid of vegetation. It is, like the Barracouta Rocks, the remnant of a larger island, which must have covered the greater part of the bank to the north of the eastern end of Bahama Island. Little Sale Cay, the Barracouta Rocks, and the Centre of the World, standing as they do as the outposts most exposed to the agency of the waves, are cays and patches of rocks the outlines of which have been far more affected by the action of the sea than the more eastern range of inner cays, which protect the eastern extremity of Little Abaco.



LITTLE SALE CAY ROCKS.

Grand, Double Breasted, Stranger, Carter, Fish, Pensacola, and the Hog Cays are, in the order named, the westernmost of the long line extending from Walker Cay Channel on the northern edge of the bank along its eastern edge as far as Cheroki Sound near the southeastern extremity of the bank. This line of cays protects the eastern face of Little Abaco and of Abaco from the action of the heavy trade wind swell which pounds upon the eastern face of the cays; they will in time disappear completely, as the intervening channels become wider, thus exposing their western face to the long reach of the sea, which has already removed nearly all traces of the former line of outer cays, islets, and sheltered cays which must once have formed the continuous Little Bahama Bank, — then a bank on which were many islands, and which was fringed on its sea face by cays of which no trace is now left except the shallower patches on the banks to indicate their former existence. The outer line of cays is flanked on the sea side by the narrow flat of the bank between them and the 18 or 20 fathom line, where the bank drops suddenly to a hundred or a hundred and twenty fathoms. On this flat coral reefs flourish, as more or less extended patches of heads or clusters of heads, in a depth of four to six fathoms. Inside of this line the corals do not flourish well, being too much exposed to the full force of the Atlantic swell. This belt of corals we crossed twice, on going off the bank at Green Turtle Cay, and again on attempting to enter Little Harbor.

The inner shore line of the outer row of cays is generally formed by low vertical cliffs, behind which rise the rounded summit lines of the cays, scarcely reaching at any point a greater height than fifty feet. All these islands are of æolian origin, the rocks composing them differing in no wise from those of the other parts of the Bahamas. The character of the bottom, however, changes somewhat after we approach the Barracouta Rocks. There it begins to be somewhat more marly, and soon after going eastward we enter a district the bottom of which is characterized on the charts as marly; finally, when we get off Green Turtle Cay, we find that the marl closely resembles the peculiar white ooze covering so great a part of the bank to the westward of Andros. This white marl fills the channel all the way from Little Abaco to Man-of-War Channel. The samples of the bottom taken off West End Rock of Little Abaco, in three fathoms of water, are fine marl of a light gray color, and of a consistency almost like plaster of Paris, but of a bluish tint. Off the eastern face of the outer cays the bottom is covered by the coarse sand formed of coral débris and of æolian rock, or even of large pieces, according to the conditions due to the outer line of protecting reefs. The outer line of cays forms a sort of sieve through which the action of the sea outside due to the prevailing winds is greatly modified and tempered both upon the western face of the cays and the eastern channel face of the Abacos.

Steaming along in an easterly direction, keeping Little Abaco to the south, the island is covered with low growth, the cliffs of the eastern face are not prominent, and the æolian rocks can be seen at all exposed places on the sides of the cay which are bare of vegetation.

To the eastward are seen the outline of the low rounded hills of Spanish and Powell Cays, the latter about eighty feet in height, off Great Abaco. South of Spanish Cay the bottom consists of very fine marl, and is covered with sponges, coralline algæ, Thalassia, and several species of Penicillus.

After passing the spit at the north end of Great Abaco the island widens somewhat, so that we get two lines of æolian hills parallel to the shore. The western range, which is the highest, is covered with low vegetation. Nearer the shore the trees are taller, seemingly mastic and mahogany woods, while from the south the pines come in again, and the southern part of the island, which falls off rapidly to a low flat from Mango Hill, is covered with a thick pine forest, which extends unbroken to Rocky Point. About opposite Munjack Cay the shore æolian hills, which run south from Angel Fish Point, are not more than from four to six feet in height. Farther south they rise to twenty or twenty-five feet, and pass into the flats upon which the pine forest extends, as we could see when steaming from the Woollendean Cays on the inside of the bank towards the western shore of the island.

After Powell Cay comes the narrow line of Munjack Cay, and next Green Turtle Cay, the most important settlement of the Bahamas after Nassau. Seen from the west all the cays appear to be low æolian hills with rounded outlines. Green Turtle Cay is a little more than seventy feet in height. It is somewhat broader than any of the other outer cays. There is a fine bluff of white æolian rock at the southern extremity of the island. The base of the cliff is constantly eaten away by the action of the sea, and supplies the material from which is derived the whitish marly bottom which extends over the channel to the east of Great Abaco. No Name Cay protects the anchorage of Green Turtle Cay from the outside swell to the south, and Munjack and Crab Cays protect it from the north. Owing to the short distance between the outer cays and Great Abaco the sea in the channel acts upon its shores with little force.

An examination of the larger charts of this part of the Bahamas will show the effect which subsidence has had in forming a number of boat harbors and inlets on the shores of this cay. Some of them have twenty feet of water, and are more or less protected by the patches of coral reef growing between the cay and the edge of the bank. Upon these patches the sea beats violently, forming two or three lines of breakers, through which it is often impossible even for small boats to find their way out. Similar sinks exist upon many parts of the Bahamas, one of the most characteristic of which is Hurricane Hole, south of Andros (Plate XI. Fig. 4).

After leaving Green Turtle Cay, immediately along the sea face of the Little Bahama Bank on our way south, we passed through great masses of gulf-weed. There is little doubt that much of the Sargassum we meet with in the Bahamas comes from the shores of the cays. It is found in considerable profusion in many localities, and, while growing vigorously during the comparatively short season of calms, immense quantities are torn off during gales or heavy seas, so that a fresh stock of Sargassum must at all times be increasing the mass floating in the range of the Gulf Stream and of the northern extension of the equatorial set. How long it can thus float, and perhaps propagate by budding, is not known. It is, however, a well known fact, that Sargassum torn off from the rocks can be kept thriving for months in tanks or dishes.

The slopes of the low shore hills of Great Abaco, as seen extending southward from the anchorage at Green Turtle Cay, show in a most characteristic way their æolian structure. The base of these hills is cut off by low vertical cliffs which have been formed by the gradual wearing away of the rocks by the sea. We examined the shore of Great Abaco at Black Point, pulling round it and landing inside on the sand beach formed behind the spit. The rocks present the same æolian structure, and are greatly worn by the breakers. The material back of the beach is more in the amygduloid stage than in the marl stage. In three and a half fathoms off the beach the bottom is somewhat more sticky than the cleaner samples taken immediately on the beach.

In our way out through Whale Channel Cay we found all the islets and rocks rounded off on the summits, the surface pitted and honeycombed and eaten away at the base of the rocks.

From the summit of the white cliff to the eastward of the landing on Green Turtle Cay we could see the breakers on the outer coral reef, which extends more or less parallel with the edge of the bank all the way round its eastern edge in a nearly unbroken line.

## Whale Cay Channel and the Eastern Face of the Little Bahama Bank.

**Plate X. Fig. 1; Plate XI. Fig. 7.**

Passing out through the channel and crossing the opening left in the reef through the breakers, we had a fine exhibition of the skill and coolness of the pilot as he steered the "Wild Duck" into deep water.

Whale Cay Channel Rock is but a small outlier of a sunken patch. Whale Cay, as seen end on, shows the æolian hills to have their longest slope on the east face, and the same structure is admirably shown for Great Abaco. Great Guana Cay displays the same feature, though here and there short stretches of the base of the shore hills are eaten away into low vertical cliffs, probably opposite smaller or greater gaps in the belt of coral heads protecting the outer islands from the terrific pounding of the trade wind swell. Where not cut away the lower part of the shore hills is pretty well covered with coral sand torn off from the reef and thrown up on the shore. Great Guana Cay is covered by a most scanty vegetation near the shore, but is a little better wooded on the hill face near the summit.

Between Great Guana and Elbow Cays is a series of low cays, rocky or sandy, with very little vegetation near the summit ridge. The line of breakers forms a continuous wall with the islets whenever there is a heavy swell running, as was the case when we steamed past.

Man-of-War Cay has the same characteristics as Great Guana Cay. It has a high sandy beach with an occasional rocky outcrop covering the underlying rock, and the usual scanty vegetation just above high-water mark becoming somewhat thicker near the ridge of the island.

The succession of æolian hills piled up one by the side of another and sloping up to the westward is clearly seen in the line of Man-of-War Cay and of Elbow Cay. The settlement on Elbow Cay is protected by an outlying line of rocks, a part of the former eastern extension of that island, which now forms an outside line of islets connecting it with Man-of-War Cay.

As we steamed down towards the south end of Elbow Cay the face of the northern ridge above the settlement was seen to be white æolian rock cropping out between the bushes and scrub vegetation. All the way from Whale Cay we were running parallel with the belts of coral reef and the outer line of rocky cays. Near the south end of one of the small cays, between Tilloo Cay and Lynyard Cay, there is an accumulation of large rocks opposite one of the gaps in the reef and in the outer line of rocky cays, giving the sea full swing to throw up the fragments of the æolian cliffs as they become broken off.

The east face of Lynyard Cay is low and worn into low cliffs. In the background can be seen the pine forests of Great Abaco rising behind Tilloo Cay Sound. The last of the outer islets we were near enough to examine made the northern spit of the entrance to Cheroki Sound, while Ocean Hill, a promontory of Great Abaco, formed the opening to Little Harbor to the south of Lynyard Cay. As we lost Great Abaco, the eastern face of which is no longer protected by outlying islands, we could see the comparatively high vertical cliffs extending southward in a nearly unbroken line to the point which we had seen on our first reaching the island north of the Hole in the Wall.

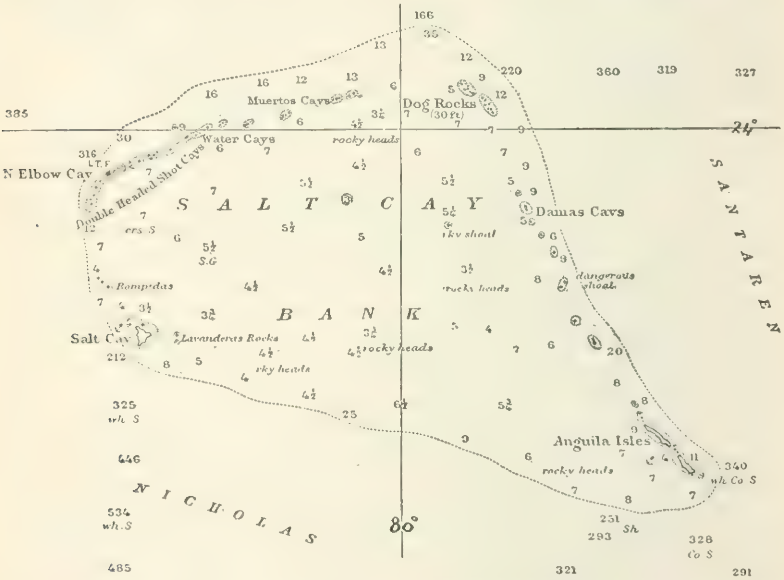
## SALT CAY BANK.

**Plates I. and XXXI.**

Before describing the banks to the eastward of the Great Bahama Bank I will give a short account of Salt Cay Bank, the westernmost of the three banks lying on the eastern edge of the Gulf Stream. Salt Cay Bank is triangular, with rounded angles, its greatest width being about forty miles and its length nearly sixty. It lies at the western opening of the Old Bahama Channel, the forks of which, separating the bank from the Great Bahama Bank and Cuba, are known as the Santaren and the Nicholas Channels. In general, Salt Cay Bank resembles more the Crooked Island and Caicos Banks, and has reached a condition intermediate between them and the Mouchoir and Silver Banks. There remain on the edge of Salt Cay Bank fewer islets and rocks than along the Crooked Island and Caicos Banks, but they have not disappeared so as to leave mere rocks awash, as upon the edge of Mouchoir and Silver Banks.

Salt Cay Bank has been described by Professor Agassiz in his Report to the Superintendent of the United States Coast Survey for 1851, and republished in the Memoirs of the Museum of Comparative Zoölogy. Having visited the Florida Keys first and Salt Cay next, he naturally extended his explanation of the formation of the Florida Keys to all the cays of Salt Cay Bank. The structure of Salt Cay is, I believe, however, radically different from that of the other cays of the bank which I visited.

It is, like Cay Lobos, built of recent coral sand rock accumulated after the formation and disintegration of the cays of the bank. It is on the very edge of the bank, and owes its existence to the throwing up at that point of coral sand so as to make an island, the underlying base of which there is every reason to suppose does not differ from that of the other banks of the Bahamas. This we may safely infer after an examination of the remaining outcropping islands forming the Double Headed Shot Cays, the Muertos Cays, the isolated islets of the eastern edge of the Salt Cay Bank (Dog Rocks and Damas Cays, etc.), and the Anguila Islands. The shores of Salt Cay are edged with strata inclined to the sea, composed of recent coral rock sand of different degrees of fineness, including in some cases excellent examples of coarse heavy breccia. At another point on the shore we found a mass of broken fragments of Strombus and Turbo of all sizes and shapes, rounded, elliptical, or angular, often more or less worn, forming a regular coarse conglomerate. Mixed with this are numerous pieces of bivalves. At other places the fragments of shells have been broken to very small pieces, forming a very fine breccia.

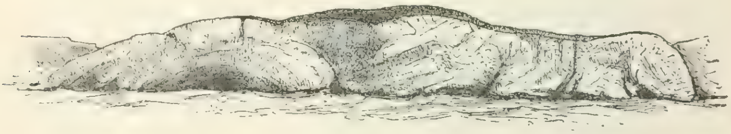

Muertos Cays
Dog Rocks
(30 ft)
Water Cays
rocky heads
N Elbow Cay
LT. F
Double Headed Shot Cays
SALT CAY
BANK
Damas Cays
rky shoal
dangerous shoal
rocky heads
Rompidas
Salt Cay
Lavanderas Rocks
rky heads
rocky heads
Anguila Isles
rocky heads
NICHOLAS
SANTAREN
24°
80°
166
35
220
360
319
327
385
316
212
325
wh. S
446
534
wh. S
485
340
wh. Co S
251
293
Sh.
328
Co S
321
291

The Salt Lagoon, which was once the basis of a thriving industry, destroyed by the hurricane of 1866, is separated from the sea by a long steep beach, the summit of which is from twelve to fifteen feet above the level of the sea. The sea face is not more than twenty to thirty feet wide, while on the lagoon side the beach is from three to five hundred feet wide. As has been noted by other observers, the water of the lagoon is intensely salt. We saw nothing living in it, but many dead conchs and the shells of other large mollusks, as well as those of innumerable smaller mollusks were found scattered all along the lagoon beach. These mollusks must have lived in the lagoon during a higher stage of water, when its salinity did not differ materially from that of the sea. It is surrounded by mangroves, many of which run far into the lagoon. The hills to the east are not more than twenty-five feet in height. I could not satisfy myself of their true character, and could not decide from what I observed whether the rocks composing them were æolian, or whether they had been thrown up during hurricanes, as was undoubtedly the case with a bluff which forms a part of the same low range separating the lagoon from the sea. This bluff was built up of large rectangular blocks of coral rock similar in structure to that of the inclined strata along the shores. Some of the blocks had been thrown up to a height of fully twenty-five feet above the level of the sea during the hurricane of 1866. At least our pilot says that is the general report.

Between Salt Cay and Double Headed Shot Cays as far as Rompidas Rocks we steamed on the edge of the bank in about seven to eight fathoms over masses of coral heads closely clustered together, separated by narrow sand bars consisting of Astræans and other corals. At our anchorage off Salt Cay the coral heads were growing luxuriantly in from three to five fathoms. The great abundance of living corals on the edge of the Salt Cay Bank fully accounts for the masses of fragments of corals in all stages of comminution which we found on the beach of Salt Cay, and for the formation of an island like Salt Cay, which is probably wholly of reef-rock sand origin, and not of æolian origin like the other cays on the northern and eastern edges of the bank. After making the shallower water of the bank, the coral heads are fewer, there are longer stretches of sand between the heads, and large spaces entirely devoid of corals.

Salt Cay Bank is, like the other banks of the Bahamas, a triangular plateau fringed on the eastern and northern edges with islands and islets or isolated rocks all of æolian structure, while on the western edge of the bank, with the exception of the Rompidas and Lavanderas Rocks, they have disappeared. The subsidence of the bank has probably been fully as great as that of many of the other banks, if we are to judge by the condition of the Double Headed Shot Cays and of the Anguila Islands.

The Double Headed Shot Cays, as approached from the south, present one mass of isolated rocks, islets, and islands without vegetation. Elbow Cay (Plate XXXI.), the largest island of the group, is a splendid specimen of the transformations to which the æolian rocks of the Bahamas have been subjected. The surface of the island is deeply pitted and honeycombed in all directions. Near the edge there are many blow-holes, through which the spray is sent in all directions, and on the north side, where the water is deepest, the action of the northers must have been one of the principal causes of the wearing away of that part of the island. The æolian structure of the rocks of the island could be most plainly seen. At the landing to the south of the lighthouse, as well as in the deep channel for landing stores cut into the rock on the north side, the stratification so characteristic of æolian rocks was most distinct. Steaming across the bank towards the Anguila Islands we found the bottom on Salt Cay Bank much like that of the other Bahama Banks, with little animal life but many coralline algæ. We dredged a few times on the way, bringing up many fragments of shells and broken Clypeastroids showing the effect of the waves on this shallow plateau. The outlying rocks to the northwest of the Anguila Islands could plainly be seen to be of æolian origin. The islands are comparatively low, the northern and southern extremities being somewhat higher than the central mass of the islands. The long stretches of low vertical cliffs forming the western shore of the islands are separated by sand beaches. The hills near the southern extremity on the west shore mark the highest part of the islands. Opposite our anchorage were fine æolian hills from forty to fifty feet in height, full of cavities and deeply honeycombed.



ÆOLIAN CLIFFS, SOUTH ANGUILA.

## THE EASTERN BAHAMA ISLANDS.

**Plate I.; Plate VI. Figs. 1 to 4; Plate IX.**

To the eastward and southeastward, and separated from the Great Bahama Bank by very deep channels, are a series of islands and banks extending from Watling Island to Navidad Bank, which in their turn rise sharply from the bottom of the ocean. These islands and banks are of all shapes, either elliptical, or circular, or more or less rectangular, or sometimes irregularly triangular. They are interesting as showing the different stages through which the Bahamas as a whole have passed, from the time when they covered a far greater area than that now indicated by the islands, which in some cases merely form the sea fringe of the banks of which they represent the summits. The former islands have been eroded and eaten away, and have wholly disappeared on the western faces of the banks, or have left only here and there a small island or isolated rock to testify to the former existence of the same æolian hills which form the summits of the present islands.

The smaller islands — like Watling, Conception, Rum Cay, Atwood Cay, the Plana Cays, Mariguana, and the Inaguas — still occupy nearly the whole area of the banks upon which they rise. The 100 fathom line of Great and Little Inagua, of Samana, and of Mariguana, is but a little distance beyond the shore line of these islands. On Rum Cay and Watling the 100 fathom line bank is somewhat larger, and Conception Island is a small part of the submerged bank upon which it rises. But except Conception these islands have at no time differed very materially from their present outline. When, however, we come to such banks as the Crooked Island Bank, Caicos Bank, and Turk's Islands, we find upon them a series of islands which have been greatly modified by the action of the sea. The islands, such as Crooked Island, Fortune Island, Bird Rock, the Fish Cays, Acklin, and Castle Island, which, with the exception of the westward face, nearly surround the Crooked Island Bank, are all that remain of the one large island which undoubtedly once occupied the whole of this bank even somewhat beyond the 10 fathom line. In fact, we may well imagine the time when the Crooked Island Bank presented much the same appearance as Great Inagua, when it had like the latter its fringing reef a short distance from the shore line at a depth of four to fifteen fathoms, and formed perhaps here and there a reef harbor like that of Alfred Sound at the northwest extremity of Inagua.

The æolian hills of the western face of the former Crooked Island land were probably quite low, and were soon eaten away. As the bank subsided, the great lagoon or flat occupying once the central part of the island, as at Inagua, sank below the level of the sea to become the bottom of the bank, while the low land to the westward was all washed away and disintegrated by the action of the sea and rains.

We can readily trace a similar course of events on Caicos Bank, and find no difficulty in reconstructing the Caicos Bank land. This is now split up into West Caicos, Providenciales, and North, Grand, and East Caicos, which form the northern and northwestern outline of the bank, while South Caicos, Long Cay, Ambergris Cays, and the Swimmer Rock fringe the eastern face of the bank, and Molasses Reef, French Cay, and West Sandspit are the remnants of the land fringing the southwest line of the Caicos Bank. Here and there on the southeastern part of the bank rise the Seal Cays, Pear Cay, White Cay, and the small rocks which were once a part of the greater Caicos land. The bank itself, like Crooked Island Bank, the Turk's Islands, in fact all the banks, not excepting the Great Bahama Bank, show a dip to the westward, and the same is the case with the sunken Mouchoir, Silver, and Navidad Banks. Great and Little Inagua evidently have not been subject to the same amount of subsidence which has so materially affected the islands and banks to the seaward.

In addition to these larger banks we have Mira por vos Bank with a few insignificant cays, Diana and Brown Banks, both of which are sunken, the one with ten, the other with nine fathoms in the shallowest part. To the southeast of Turk's Islands are Mouchoir and Silver Banks, on both of which there are rocks awash and coral heads on the northern faces of the banks, with a few isolated rocks irregularly scattered, the depths on their banks ranging from nine to twenty fathoms; and finally comes the last sunken bank to the eastward, Navidad Bank, with an average depth of about sixteen fathoms and a least depth of eleven fathoms.

## Watling Island.

Plate IX. Fig. 12; Plate XXIII.

Watling, as is seen from the chart, is twelve miles long and from five to seven wide. Its shores are but slightly indented. The greater part of the surface of the island is occupied by salt water lagoons of very irregular outline, formed in the valleys and sinks of the cross ranges of æolian hills covering the island. These hills rise to a height of from a hundred to a hundred and forty feet, and are covered with woods.

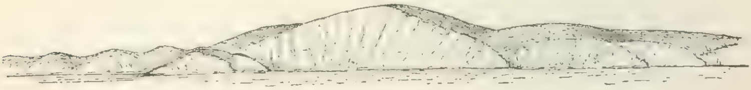
An examination of the map of Watling Island is interesting as showing the great number of lagoons which occupy so large a part of its surface. On the western side is found the largest of these lagoons. It is quite shallow, the part we examined varying between one and a half and three feet in depth. An artificial cut has been made through a low ridge separating one of the western lagoons, about half a mile from Riding Rock beach, so as to make a boat passage to the larger lagoon and reach by water the vicinity of the lighthouse on the northeastern extremity of the island. The cut shows the same æolian structure of the rock so characteristic of the islands we had so far visited. In the distance, on the opposite side of the lagoon, could be seen rising the same solidified æolian hills which characterize the structure of all the islands on the larger banks. The examination of this side of Watling Island plainly shows its structure to be similar to that of the islands to the westward, and also shows that Watling owes its present configuration and the existence of its many lagoons to the subsidence which has caused the gradual disappearance of the extensive tracts of æolian land which once covered the greater part of the Bahama Banks.

The bottom of the great lagoon is thickly covered with algæ (Acetabularia), and the shores of its beaches are lined with diminutive specimens of the same species of shells found on the open sea beaches. The water of the lagoon is intensely salt. It connects evidently with the sea, as our guide mentioned several blow-holes through which the tide is forced into the lagoons.

The shores of the lagoon are lined with mangroves. Parts of the lagoon have been separated from the sea by a high narrow beach thrown up by the incessant Atlantic swell; but by far the greater number of the lagoons of Watling Island are due to the general subsidence of the island, forming drainage areas, and allowing the sea to cover the flats intervening between the ranges of æolian hills and then to the closing of these openings by coral sand beaches thrown up by the sea. Many of the ponds are disconnected, are salt, and are supplied by percolation through the barriers separating them from the sea, or by blow-holes connecting them directly with it. This is especially the case with some of the ponds only separated from the sea by narrow beaches, Many of the lagoons are in underground communication with the sea. and in some of them the position of the blow-holes through which the sea water is forced up can be traced by the commotion of the water of parts of the lagoon.

The subsidence and erosion of the island have formed an extensive harbor at the northeastern end, hemmed in on all sides by islands and islets, leaving a couple of passages to the northeast of Green Cay into Graham Harbor. Fringing this harbor, and following its outline in from three to six fathoms of water, extensive patches of corals are met with which form to the eastward a more or less continuous coral reef, with an inner protected passage for boats and smaller vessels along the whole of that face of the island. These independent patches of corals are also found on the west coast, as at Riding Rocks, but are not so continuous as on the east coast. The corals forming these patches are the common West Indian species of Madrepores, Mæandrina, Astræans, and Orbicellas, with Flabellum as the most common of the Gorgonians. Sailing round Graham Harbor, we followed a course parallel to the eastern shore. The outer reef shelters the long sand beaches fairly well, and the former outline of the island was such that there are but few vertical bluffs on the windward side of the island. The highest hills are on this eastern side, one rising to the southward of the lighthouse, its sea face forming the white bluffs which, according to Captain Becher of the Royal Navy, flanked the beach where Columbus first landed, while the spurs from Fortune Hill nearer the southern end of the island extend to the sea and form the white cliffs which according to Sir Henry Blake flanked to the north of Columbus Bight the spot where Columbus first landed in the New World. The beach at the northeast end of the island is so entirely shut out by patches of coral reefs that it would have been impossible for Columbus to have anchored at the spot which Becher assigns as his anchorage. Our pilot says no sponger ever dares to anchor there; while farther south, at Columbus Bight, the spot selected by Sir Henry Blake, there is a small reef harbor where boats of the size of the caravels could readily

LANDING PLACE OF COLUMBUS, ACCORDING TO CAPTAIN BECHER, R. N.



LANDFALL OF COLUMBUS, ACCORDING TO SIR HENRY BLAKE.

find an anchorage, and from which the boats of the fleet might have rowed in safety to examine the "other side," and return the same day to their ships.

I may here quote from a translation, by Mr. H. L. Thomas of the U. S. State Department, of the Journal of Columbus,[1] the following points of interest regarding the so called barrier reef off the east face of Watling Island: "Went along the island, in a northeasterly direction, to see the other side, which was on the other side of the east. . . . I was afraid of a reef of rocks which entirely surrounds that island,[2] although there is within it depth enough and ample harbor for all the vessels of Christendom, but the entrance is very narrow. It is true that the interior of that belt contains some rocks, but the sea is there as still as the water in a well."

From Columbus Bight on the east coast there is an excellent boat passage inside the reef leading to Graham Harbor, and it is within this passage that the boats of Columbus probably rowed to explore the other side of the island. It is undoubtedly to this passage, sheltered by the reef, and to the reef harbor, that he refers as capable of holding the navies of the world. Such a wonder as a reef harbor or a passage inside a barrier reef could not fail to strike him, and it seems strange that it is not better described in his journal, and that so little is said by him of the striking contrast of the light green color of the water inside the barrier reef and in Graham Harbor with the dark blue of the ocean beyond the 100 fathom line.

The 100 fathom line extends about a mile beyond the reef. Inside the reef, the passage is on an average about a third of a mile wide. The 100 fathom line runs at a fairly uniform distance from the shore all round the island, except off the Hinchinbroke Rocks at the southeast end, where the bank extends seaward more than two miles, and comes in again along the south shore to Southwest Point.

Along the west coast disconnected patches of coral heads extend from a depth of three or four fathoms towards the edge of the bank. We came to anchor that same day at Southwest Point on the steep slope of a sand beach. Here we also found, in from four to twelve fathoms of water, outside the action of the breakers, fine patches of Madrepores and other masses of corals furnishing material for the recent coral beaches which form a low plateau flanking the æolian hills. This plateau lies at intervals between headlands along the western face of the island.

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[1] G. V. Fox, Appendix 18, U. S. Coast and Geodetic Survey, Report for 1880, p. 14.

[2] Not the west side.

## Rum Cay and Conception Island.

**Plate IX. Fig. 11.**

From the southwest point of Watling Island we steamed to Rum Cay, the structure of which is very similar to that of Watling. The salt ponds are limited to two small areas, from which formerly a considerable amount of salt was exported.

On our passage from Watling Island to Rum Cay, and while sailing round it and on our way to Clarence Harbor, we passed through many streaks of gulf-weed.

The bank of which Rum Cay forms the summit extends northeast about five miles to the 100 fathom line. The bank is narrow on the west face. On the north side the 100 fathom line is not quite two miles from shore, and varies from three miles to three and a half on the west and south sides. On the eastern side the salt ponds are separated from the sea by æolian hills varying from fifty to ninety feet in height, and on the south by walls of recent coral sand. The northern and western ends of the island are also capped by æolian hillocks.

Rum Cay is about nine and a half miles in length by five in breadth at the east end and two at the west. The southern side of the cay is edged by a coral reef nearly a mile off shore, growing upon sunken patches of æolian rocks. A wide entrance through the reef forms Port Nelson inside the reef with four fathoms of water. There are patches of corals all along the north shore about half a mile from it. The corals are thriving, and consist, as far as we examined them, mainly of huge masses of Astræans, Orbicellas, Madrepora palmata, and Millepores.

The low southeastern part of the island is formed of débris of the reefs now growing on the southern edge of Port Nelson. A low bank of coral sand is thrown up, forming strata slightly inclined and protecting the coral sand flat extending inland to the base of the æolian hills. The north face is bold, steep, with low bluffs and no anchorage along it. The east face is flanked by low æolian hills. The highest hills are along the northern side near the northwest extremity of the island.

Conception Island we did not visit. The adjacent cays rise to one hundred and thirty feet above the circular bank, which carries from six to fourteen fathoms of water. Reefs extend in a nearly unbroken line round the southeastern and western edges of the bank. It is probable that the 1,000 fathom line connects Conception Island Bank with the southeastern side of Cat, and that Rum Cay also lies within that line.

## The Crooked Island Bank.

**Plate IX. Figs. 1, 9; Plate X. Fig. 4; Plates XXXVII. and XXXVIII.**

The most westerly of the smaller outlying banks of the Bahamas is the Crooked Island Bank, which is triangular in shape. Its northern side is about thirty miles long, its eastern face forty, and the western forty-eight miles. The bank slopes very gradually towards its western and southern edge. The 100 fathom line runs close to the edge of the bank along the sea face of both Crooked and Acklin Islands, as well as to the west face of Fortune. This and Caicos Bank are, as it were, epitomes of the Great Bahama Bank, representing on a small scale the characteristic physical features of the Bahamas. Fortune Island forms the western edge of the bank, Crooked Island the northern, and Acklin and Castle Island part of the northern and eastern face of the triangular bank, which is open to the sea for the greater part of its western side. The islands forming the outside edge of the bank are all narrow; both Crooked and Acklin Islands are somewhat wider than Fortune Island, spreading out on the northern and western sides very gradually, and passing into the shallow waters of the inner northeastern part of the bank. From the western extremity of Crooked Island extends a wide range of æolian hills, the Blue Hills, occupying the central line of the greater part of the island; the summits reach a height of about two hundred feet. Near the eastern end Mount Pisgah rises to two hundred feet close to the shore.

The whole northern face of the bank is edged by a coral reef extending from Northeast Breaker on Acklin Island to Bird Rock, where the reef forms a well sheltered basin. About a mile from the northwest point of Crooked Island is Portland Harbor, with three to four fathoms of water.

Acklin Island is separated from Crooked Island by a wide passage of about two miles, but very shallow. The eastern face of the island is skirted by a reef nearly continuous from Northeast Point to Castle Island, beyond the southern extremity of Acklin Island. Castle Island stands on the southern end of the Crooked Island Bank, and is about two miles in length. On the northern and eastern sides of Acklin Island are a series of æolian hills lying along the eastern face, which rise to a hundred and fifty or two hundred feet. Near the southern extremity they are somewhat higher than those of Fortune Island.

The west shore of Acklin, like the southern shore of Crooked Island, is low, running into the shallow water of the bank. Nowhere, except near the southern end of Fortune Island and to the west of the Fish Cays, and a small patch to the eastward of them where there are two fathoms, is this shallow water of greater depth than one to one and a half fathoms, and a great stretch of the bank carries even less than that.

Acklin Island and Castle Island, as seen from the southeast, presented no features differing in any way from those of the other Bahama Islands. Vertical bluffs of æolian rock, of greater or less height, characterize their sea face. The trend and outline of the æolian hills of Acklin plainly indicate their origin.

Fortune Island is nine miles long, comma-shaped, barely a quarter of a mile wide at its northern extremity. Near the south end a hill rising to a hundred and ten feet slopes gradually towards it. Off the east coast near the south end there is a deeper belt of water running rapidly into six or seven fathoms. From the southwest end of Fortune Island a narrow reef extends along the whole western face, in from four to twelve or fifteen fathoms, towards the edge of the 100 fathom line bank, which drops off abruptly from the outer edge of the reef. The Fish Cays are the only remnants of the land once skirting the southern part of the western edge of the bank, or perhaps of the land which once covered the whole bank, and of which the larger islands are the vanishing tops. To the eastward they are surrounded by a series of sand bores which do not quite reach the surface at low water. Off the west coast of Fortune Island the 100 fathom line runs close to the shore, leaving but a narrow belt of soundings. This belt widens out somewhat about half-way north along the west shore, and from that point an irregular coral reef extends, in from three to five fathoms, almost to the northern end of Crooked Island. The western end of Crooked Island is cut up by narrow lagoons opening on the bank side. The inner one opens by two channels edged with mangroves into a large inland bay nearly ten miles across. The outer one is separated from the Crooked Island passage by a narrow band of recent coral sand. This gradually disappears as one goes farther on the bank, until finally the bottom is made up of the débris of æolian rocks mixed with fragments of shells, and other Invertebrates, the whole kept more or less in place by the numerous calcareous algæ which flourish on the limestone bottom.

On entering the bank off the southern extremity of Fortune Island we found the bottom to be dotted with coralline algæ, fine sand, and with patches of the common West Indian Gorgonians. The corals on the bank exist in irregular patches, and do not extend any distance eastward. They flourish along a narrow belt on the edge of the bank, between three to six and fifteen or sixteen fathoms.

On the bank side of Fortune Island the slope of the hills runs insensibly into shallow water; but, steaming on the western face, the shores all the way from the South Spit of Fortune to its northern extremity are flanked by low æolian cliffs interrupted by steep coral sand beaches. Above the low cliffs extends for a considerable distance a line of angular rocks thrown up above high-water mark by an unusual swell or by hurricanes.

The lagoon which extends south from the settlement nearly to the southern end of Fortune Island is separated from the sea by a high steep coral sand beach (Plate X. Fig. 4). The beach becomes gradually much lower north of the settlement; it extends all the way to the northern extremity of Fortune Island, and is again seen on Crooked Island, being nearly unbroken along the whole shore line as far as Portland Harbor at the northern end of the island. Crooked Island is also built of æolian hills with gentle slopes to the west except near its northern spit, where the shores consist of low vertical cliffs.

From Bird Rock lighthouse the beautiful sweep of a coral reef connecting it with Crooked Island forms a fine bay sheltered from the northeast trades, the green waters of which stand out in marked contrast with the dark blue of the deep water off the bank, while the white wall of breakers marks the dividing line between it and the deep water to the east.

If Columbus visited Bird Rock, or Cape Beautiful, as some writers call the western end of Crooked Island, he could not have failed to notice a physical phenomenon so strange to him as that of a coral reef forming a bay well protected from the prevailing winds, nor could such a sharp observer have failed to describe at length, or to note at least, this peculiar feature of the sea.

To the westward of Castle Island is the Mira por vos Bank, with soundings near the edge of from five to nine fathoms. It is pear-shaped, with a cluster of low barren rocky cays, the highest of which is but thirty feet. At the north end they are connected by a reef; and there are several disconnected patches of corals, with three fathoms of water over them.

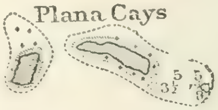
Two other small banks rise in the Crooked Island passage. Diana Bank, twenty miles to the west of Fortune Island, is about four miles in length, in from nine to fifteen fathoms of water. The bank is said to consist of sand and of coral. South of Mira por vos Bank rises the peak of Brown Bank (Kansas Bank), which has from ten to twenty-three fathoms of water on it. Both these banks drop abruptly into deep water from the 100 fathom line, close to the soundings indicated.

A number of other small banks have also been reported, but their position is doubtful. They are Cuidado Bank, south of Mariguana, the Clarion Bank, south of Mathew Town (Inagua), the Fawn Shoal, south of Turk's Island, and the Severn Shoal, to the northeast of Silver Bank. It is not astonishing that, in a district where the currents are so strong and so variable, it should be difficult to find the position of reported shoals, the original positions of which are generally very inaccurate.

## Mariguana, the Plana Cays, and Samana.

**Plate I.; Plate IX. Fig. 4.**

On account of the strength of the trades we did not visit Mariguana, Samana Island, or the Plana Cays. The highest point of Mariguana is stated to be a hundred and one feet, and at the east end there are several hummocks of from forty to sixty feet. The hills, I am informed, consist of the regular Bahamian æolian rocks, and the same rocks also occur on the Plana Cays. The north shore of Mariguana is skirted for its whole length by a reef. The west shore is bold, and the 100 fathom line of the bank is close to the land. The south shore, with the exception of a reef which protects Abraham Bay, is clear; the bottom is covered with clean sand. At Southeast Point a reef of nearly nine miles in length extends to the easternmost extremity of the spit formed by the bank off the eastern face of the island. The reef is close to the 100 fathom line on the south side of the spit, but on the north side it is half a mile distant.

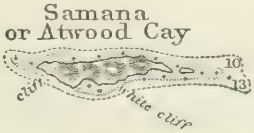


Lat. 22° 40′ N.; Long. 73° 34′ W.

The eastern side of the West Plana Cay is fringed by a reef, while both the north and south sides of East Cay are skirted by a reef about a third of a mile from the shore, and extending nearly five miles off the east end.

The highest point of East Plana Cay is about seventy feet. On the north side of West Cay the bank limited by the 100 fathom line extends about two miles.

Samana Cay is nine miles long and about a mile and a half broad. Its surface is uneven, stated by Sir Henry Blake to be perfectly barren, and the most inhospitable looking of the islands. It attains a height of one hundred feet. The narrow cay running nearly due east and west is practically fringed by a coral reef, occasionally broken for its whole length both on the north and south shores.



Lat. 23° 6′ N.; Long. 73° 40′ W.

## The Caicos Bank.

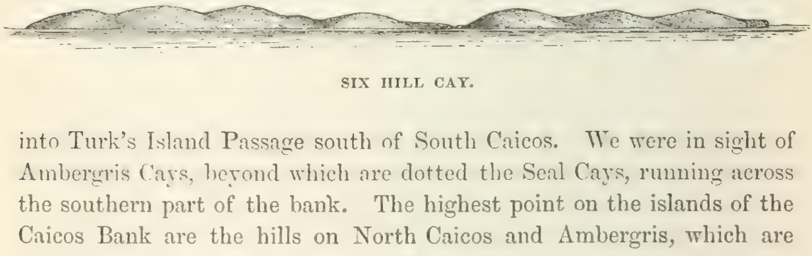
**Plate I.; Plate IX. Fig. 2.**

Caicos Bank is the largest of the eastern outlying Bahamas. Its outline is most irregular, extending sixty-four miles east and west and fifty-eight north and south. The northern and the greater part of the eastern face are edged with islands, all consisting of æolian rocks.

The wearing away of the Caicos Bank has taken place on a proportionally larger scale than on the Crooked Island Bank. The Caicos Bank is protected from the northeast trades by a line of islands extending from West Caicos east in a great curve, namely, the Providenciales, North Caicos, Grand Caicos, and East Caicos, South Caicos, Long Island, the Ambergris Cays, and Swimmer Rock, forming the only land on the east face of the bank. A few isolated patches of rocks of æolian origin rise a few feet above the surface on the southern spit of the bank, and on its west face French Cay and other shallow patches mark the outline of the former Caicos Land. On the sides facing the interior of the bank the shores of the northern islands are all low, passing into lowlands scarcely rising above the level of the sea, and thus forming most indistinct coast lines, which gradually pass into the shallow soundings characteristic of the northern part of the bank.

From the northern end of West Caicos as far as the south end of South Caicos there is on the outer edge of the bank a coral reef extending nearly unbroken along its whole length in from three to twelve fathoms of water. The reef forms a wide belt between West Caicos and Providenciales, with a narrow passage of from two to five fathoms of clear water between the reef and Providenciales. It skirts, both as a fringing and as a barrier reef, the northern shore of Providenciales, with but a narrow channel between the barrier reef and the shore. It extends along North Caicos, at a distance varying from half a mile to two miles off shore. There is a break in the reef at Juniper Hole, between the North Caicos and Grand Caicos reef. The latter extends nearly unbroken along the north side of Grand Caicos and East Caicos to Cape Comete, and thence south along the east faces of East and South Caicos. Along Long Cay the 100 fathom line is close to its eastern face, from its southern extremity the reef runs in isolated patches towards Ambergris Cays. We were unable to observe its course along the southern edge of the bank. The edging reef reappears again about twenty miles southeast of West Sand Spit, extending all the way to that point and westerly to French Cay, beyond which it forms extensive and nearly continuous reefs along the edge of the bank, such as Molasses and the Southwest Reefs east of West Caicos.

A little to the south of French Cay we entered upon the bank, passing through an opening in the edging reef, and steamed nearly east across the bank, carrying from two and a half to three fathoms of water, to Long Cay, passing in sight of Middleton and Six Hill Cays, and out into Turk's Island Passage south of South Caicos. We were in sight of Ambergris Cays, beyond which are dotted the Seal Cays, running across the southern part of the bank. The highest point on the islands of the Caicos Bank are the hills on North Caicos and Ambergris, which are said to be one hundred feet high. West Caicos is about sixty feet high. North of the track we followed in crossing the bank, as the pilot informed me, the water shallowed very rapidly, while in the direction of the Seal Cays the water is deeper.



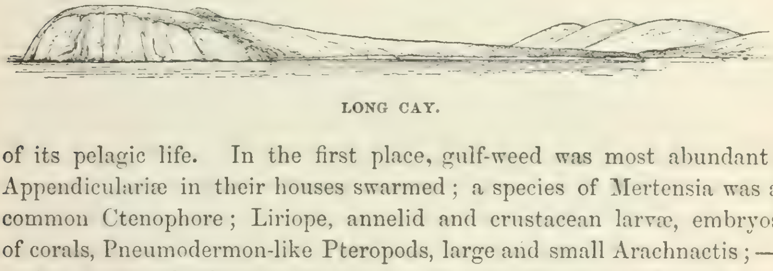
SIX HILL CAY.

The peculiar light green tint assumed by the western edge of the bank follows the belt of the edging reef, and is in striking contrast to the white bottom inside of the reef and the adjacent dark blue color of the water outside of the 100 fathom line. This color, when reflected on the edge of the clouds, is often seen at great distances; it is known to the bank fishermen as the bank blink.

Our pilot informed me that in from six to ten fathoms of water on the southern part of the east face and the southern face of the bank there are large tracts covered by a species of Thalassia, judging from his description of the weed.

We examined the bottom on the Caicos Bank on our way across from French Cay to Long Cay. As we steamed along we came upon patches of Gorgonians and of large heads of corals (Astræans) separated by long irregular lanes of sand, or nearly choked by it. The coral belt of the western face of the bank was, where we followed it, in from four to ten fathoms, although limited in extent, of a rather more luxuriant growth than on the east face of the bank. At Molasses Reef it has reached the surface, and isolated patches are exposed at low tide. The bottom consisted mainly of broken shells and of æolian sand, more or less tied together by the roots of calcareous algæ.

On leaving Caicos Bank the fine white æolian cliffs of the southeast end of Long Cay formed a prominent landmark, and gave us an excellent idea of the extent of the disintegration of all that side of the Caicos Bank land. The Turk's Island Passage is remarkable for the abundance of its pelagic life. In the first place, gulf-weed was most abundant; Appendicularíæ in their houses swarmed; a species of Mertensia was a common Ctenophore; Liriope, annelid and crustacean larvæ, embryos of corals, Pneumodermon-like Pteropods, large and small Arachnactis; — in fact, a finer display of pelagic types than we found anywhere in our cruise outside of the track of the Gulf Stream between the Cuban coast and Florida.



LONG CAY.

## Great Inagua.

**Plates I. and VIII.; Plate VI. Fig. 2; Plate IX. Fig. 3.**

Inagua is about forty-five miles long; its outline is most irregular, its greatest breadth being only eighteen miles. East Hill, the highest point on the island, stands on its east face, and is one hundred and thirty-two feet high. North of East Hill a number of hills rather higher than those of the south shore extend to Northeast Point. A number of low hills from thirty to ninety feet in height skirt the southern face of the island; when approaching them from the south, as we did in coming from Cape Maysi, they appear like distinct islands. The hills are covered with stunted bushes and palmettos. The west shore is comparatively low, Mortimer Hill north of Mathew Town being its highest point. Beyond Alfred Sound on the north shore rises James Hill, about ninety feet high, the only elevation west of Carmichael Point; flanking Ocean Bight are a number of hills from seventy to ninety feet in height. The interior of the island is low, wooded, and intersected by many salt water lagoons. A recent coral sand beach, quite steep, is the landing place of Mathew Town to the north of the lighthouse. The material for the beach comes in part from the wearing of shore coral sand rocks which extend all the way along the coast from the Lighthouse Point northward, and in part also from the fragments of the belt of coral reef which grows upon the narrow coast shelf of the island. The low plain forming the greater part of Inagua Island apparently consists of shore coral rock rising but a few feet above high-water mark, which has been deposited in the sinks between the æolian hills flanking the northern and southern shores. The æolian hills rise from the northern and western ends of the island, and increase in height to the eastward. This plain is fairly covered with vegetation and with coarse grass, and affords excellent pasturage for cattle and horses, which run wild over the island.

The eastern face of the island is skirted by a reef from six hundred feet to half a mile from the shore, the 100 fathom line being about half a mile from the reef. Nearly the whole of the south shore is also similarly skirted by a reef, with the exception of a short distance round Southwest Point on the west coast. The coral growth is in patches, the water off shore being bold and the 100 fathom line close to the land.

Alfred Sound on the east side of Northwest Point in Inagua is an anchorage for small vessels, protected by a reef nearly dry at low water, which runs out from Palmetto Point at a distance of a mile and a half from the shore. Standing at the western opening of the reef harbor are two low cays covered by a little vegetation, and connected by a reef or patches of corals and Gorgoniæ growing in the shallower water. To the eastward a long spit extends, formed by a coral reef, inside of which no less than seven fathoms are found in places. At the east end of the spit the reef is quite awash, and the course of the reef is clearly indicated by the long horseshoe-shaped line of breakers. The reef which extends east from Palmetto Point also skirts the western part of Ocean Bight. All along the shore from Palmetto Point to Northeast Point the bank formed by the 100 fathom line is very narrow. The coast is steep, and is exposed to the full action of the northerly winds.[1]

We did not visit Little Inagua. It is quadrangular in form, eight miles long by five miles broad (Plate IX. Fig. 3). Its highest point on the north side is sixty feet, and on the south side there are a few hills of nearly the same height. The northeast and northwest shores are bold, with a clear sandy bottom to a distance of about one third of a mile. There is a coral growth off the south and east sides; on the west side the bank to the 100 fathom line is perhaps a mile wide.

We may readily imagine the various banks on the Bahamas to have been somewhat in the condition of Inagua. An extensive and flourishing coral reef on the edge of the bank may have supplied the material for the formation of the great shallow bank which once existed at the foot of the æolian hills, which in their turn were formed from dry material, supplied from the shallower portions of the bank, blown into dunes and consolidated.

The outlying eastern islands, Samana, the Plana Cays, and Mariguana, resemble in their structure Watling and Rum Cay, occupying nearly the whole of the bank of which they form a part.

Neither Inagua nor little Inagua has changed its outline greatly since the subsidence took place which so materially altered the face of the line of banks from Crooked Island to Navidad Bank. Judging from an examination of the charts, it appears that, as we pass eastward from the Crooked Island Bank, the banks have been worn away generally in proportion to their easterly position. The Crooked Island Bank has in proportion to its size a greater amount of dry land fringing its border than Caicos Bank, that in its turn more than the Turk's Islands Bank, while the Mouchoir, Silver, and Navidad Banks carry more water as we pass to the east.

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[1] Dr. Henry Bryant visited Inagua in 1859, and gave a short account of the island in 1866. (Proc. Bost. Soc. Nat. Hist., Vol. XI. p. 63.) He considers the salt lake "the remains of the original lagoon which once occupied the greater part of the island, and which has been gradually filled up so evenly that the portion which still remains is nowhere more than a few feet in depth." As Dr. Bryant well says, the fertile plains are merely salt plains covered with a coarse grass dotted here and there with clumps of stunted trees, and scarcely elevated above the level of the salt lake. Dr. Bryant considered both Inagua and Watling Islands as "merely a narrow margin of an interior lagoon"; the plains as "the remains of lagoons formed by fringing reefs filled up by the action of the winds and waves."

It is worthy of notice that the position of all the important islands of the Great Bahama, Crooked Island, and Caicos Banks — as well as of Little Bahama Bank with the exception of Bahama Island — is on the weather side of the banks, either on the eastern or northern face. On the western side we find only small islets or rocks, the remnants of the western islands which were the first to disappear on the subsidence or the tilting of the western shore. This must have resulted in leaving the northwestern and eastern faces of the banks at a higher level, and must also have given to all the banks of the Bahamas a very gradual dip to the westward. This is found to be the case whether we examine the section of the bank from Andros to the Santaren Channel, or from Eleuthera to the Tongue of the Ocean, or from Long Island to the Old Bahama Channel, or that of the Little Bahama Bank from Great Abaco to Burrow Cay, or a line parallel to this from Spanish Cay to Memory Rock. The configuration of these wide shallow banks, flanked by islands on the windward face and by islets or rocks on the western face, plainly shows that the growth of the recent corals, which flourish in from three to fifteen or more fathoms almost around the whole outer face of the banks, has added very little to the amount of land, which consists wholly of æolian rock. It is only here and there that bights in the disintegrating islands have been filled as it were by the material thrown up from adjoining coral reefs, and thus coral sand flats have been formed abutting upon older æolian hills. These flats, however, form but an insignificant part of the land which remains, and play no important part in the configuration of the islands of the Bahamas.

While crossing the Caicos Bank we encountered large masses of gulf-weed.

## The Turk's Islands.

**Plates I. and VIII.; Plate IX. Figs. 5, 6.**

The easternmost of the Bahama Islands are the Turk's Islands, which rise from a narrow bank running about thirty-five miles in a north and south direction. From the middle of the bank a wide tongue extends for seven miles eastward, on which the soundings are from eight to ten fathoms. Grand Turk Island is five and a half miles long and about one mile broad. The eastern face is formed by a narrow ridge of æolian hills about seventy feet high, with their steep face on the east. The western slope of the ridge is flanked by recent shore coral rocks, which have formed the flats between the landing and the hills, and have isolated the salt ponds once the source of a profitable industry for the inhabitants. On the west side of the island near the southern end the 100 fathom line is less than eight hundred feet from the shore, and the reef which skirts that part of the island forms an exceedingly narrow belt from the 4 or 5 fathom line to the 12 or 15 fathom line. It fringes the southeastern end of the island, and on the east face extends in a mass of disconnected heads irregularly scattered over the 3 fathom line reach which stretches eastward from the shore, gradually passing into the reef which flourishes along the 4 or 5 fathom line, and which extends from Northeast Reef to Tucker Rock, along the centre of Turk's Bank, connecting all the cays of that side. On the northern part of the west face the reef is broader and has a width of from an eighth to a quarter of a mile. It increases in width on the north side, and there connects with the broad reef on the east of the island. To the southwest of the southern spit of the island a reef runs for nearly four miles which protects Hawk's Nest Anchorage. The whole of the space included between Gibbs, Long, and East Cays on one side, and from the south spit of Turk's Island to Salt Cay on the other, is filled with huge heads of corals, some of which have been described as having attained an exceptional size.[1] I am more inclined to look upon these gigantic coral heads as coral blocks of the usual size growing upon isolated pinnacles of æolian rock such as are so common in the Bahamas and the Bermudas, and which here represent the remnants of the disintegrated greater Turk's Island, which has all disappeared towards Endymion Rock.

East Cay is the highest of the Turk's Islands, the æolian hills being ninety-six feet high. Cotton Cay and Salt Cay are both formed, as is Grand Turk Island, in part of shore coral rock and in part of æolian rock. Sand Cay, the southern of the Turk's Islands, also consists of æolian rock. A coral reef runs off from the island in a northerly direction for nearly two miles.

The southernmost trace of the former Turk's Islands land is Endymion Rock, which stands isolated near the southwestern spit of the Turk's Islands Bank. From Salt Cay to the southwest spit of the bank the soundings vary from six to thirteen fathoms. The whole bank has a remarkably uniform depth, and a very abrupt slope from ten or twelve fathoms to one hundred fathoms. The bank is covered with decomposed æolian rock sand, mixed here and there with corallines.

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[1] See A. E. Verrill, Proc. Bost. Soc. Nat. Hist., 1862.

## Navidad, Silver, and Mouchoir Banks.

**Plate IX. Figs. 7, 8, 10.**

The most southerly of the Bahama banks is Navidad Bank. It has a least depth of eleven fathoms near the southeastern extremity. From the soundings it appears to vary little in depth. The southeastern part of the bank slopes off to the 100 fathom line somewhat less abruptly than either the eastern or western face. The depth on the main body of the bank varies from eleven to seventeen fathoms. It is covered with æolian sand modified by Nullipores. Navidad Bank is oval-shaped, twenty-two miles long in a north and south direction, and in the centre about eleven miles wide.

Between Navidad and Silver Banks there are three small submarine banks rising to a depth of ten, twelve, and seventeen fathoms.

Silver Bank, the next bank to the westward, is an irregularly rectangular bank. Its eastern somewhat concave side is twenty-nine miles long. The northern side is thirty-eight miles. The central part of that side, at a distance of about eight miles from the southeastern extremity, is occupied by a triangular patch of coral heads which are awash and extend nearly five miles inland, towards the northwest angle of the bank.

The west side of the bank runs nearly north and south thirty-seven miles. Coral heads crop out only at one point of this side of the bank, and also on the western part of the southern line of the bank, which is twenty-four miles long.

The soundings on the bank vary from six to twenty fathoms. The deeper soundings occur nearer the western side of the bank.

The last of the larger submerged banks is Mouchoir Bank, the outline of which is more irregular than that of Silver Bank. Its greatest length from east to west is about thirty-one miles. Its breadth north and south varies greatly. The eastern face is twenty-five miles, extending into a long narrow spit. The depth on the bank varies from seven to fifteen fathoms. On the north side there are two large patches of coral heads awash, both extending some distance south on the bank.

From what I can learn, the coral heads on Mouchoir and Silver Banks are growing upon pinnacles of æolian rock.

## Hogsty Reef.

**Plates I. and II.**

Hogsty Reef is a small atoll, irregularly elliptical; its longer axis is something more than five miles and its shorter about three at its widest part, measured approximately from the limits of the 20 fathom line. As will be seen from the deep soundings to the northwest and southwest of the reef, there is a depth of nine hundred and five fathoms not more than four miles and a quarter from the 100 fathom line to the northwest of Northwest Cay, and as great a depth as twelve hundred and eighty-one fathoms somewhat less than four miles to the south of Southwest Cay. The accompanying sketch of the reef (Plate II. Fig. 1) I owe to the kindness of Captain Wharton of the British Admiralty. It has been slightly modified from the soundings taken by the "Wild Duck" off the northeastern face of the reef. Quite an extensive plateau was developed on that side, extending the 100 fathom line more than a mile to the eastward from the position formerly assigned to it. With that exception, the shelf between the 3 fathom line and the 100 fathom line is quite narrow, and the slope most abrupt between seventeen and a hundred fathoms. It is only on the eastern edge that successive soundings were taken of ten, eleven, and twenty fathoms before reaching the 100 fathom line. Usually we might strike ten or twelve or perhaps fifteen fathoms, and the next sounding would show no bottom with the 50 fathom hand-line. The slope to the south of the atoll is slightly greater than 1 : 2.7, and that on the northern side not quite so steep, 1 : 3.1. (Plate II. Fig. 3.)

With the exception of the broad triangular shelf on the eastward side of the reef, where the corals extend out fully one mile from the breakers, the annular ring of growing corals is less than a thousand feet wide. In the lagoon itself no heads are growing except those which are found scattered between one and a half and two fathoms; these grow more luxuriantly as they get within reach of the effects of the last inner line of breakers. Here and there a head is also found in the lagoon in somewhat deeper water, but none were seen inside at any distance from the shallower parts of the reef. On the eastern face there is a stretch of corals perhaps a hundred yards in width, of which here and there a mass is exposed to the air at low tide, but as a rule there is a foot to a foot and a half of water at low tide over the shallowest part of the reef. On this narrow shelf and on its lee side are thrown up fragments of corals, or small heads, Nullipores, Gorgonians, and débris of Mollusks torn off from the outside of the reef by the incessant swell of the trade winds. Owing to the steepness of the weather shelf there are not more than two or three lines of breakers usually pounding on the reef. The corals growing to seaward are almost entirely made up of large masses of Astræans and of a few heads of Madrepora palmata. There was a greater variety of species on the lee side of the shelf, — Madrepora cervicornis, small heads of Mæandrinas, Manicina, and clusters of Millepora, as well as large patches of Gorgonians. Nullipores are most abundant on the summit of the reef, growing upon the smaller fragments of broken corals, which they also often cement together, when they are forced inward into deeper parts of the lagoon, where the cemented masses frequently form heads of considerable size.

Longitudinal and cross sections of the lagoon show that its bottom is uniformly covered with coarse sand and broken shell material, or fine sand, according to the distance from the action of the breakers. Upon this looser material algæ and corallines thrive and grow abundantly, generally in large patches. As will be seen from the survey of the atoll (Plate II. Fig. 1) the annular ring of corals within the 3 fathom line is of nearly uniform width, except that on the northern edge the belt is slightly narrower. On the shelf of the atoll, both seaward and on the lagoon side, algæ, corallines, and Nullipores are most abundant. On the sandy bottom of the lagoon the patches of vegetation consisted mainly of masses of Thalassia, Caulerpa, Penicillus, Halimeda, and Udotea, while on the lagoon coral shelf are found masses of a species of Sargassum, of Padina, Blodgettia, Laurencia, Digenea, and several species of incrusting Nullipores.[1] The heads exposed at low tide are also more abundant on the eastern face of the atoll, where there are no boat passages, while on the south face, as well as on the northwestern face near Northwest Cay, there are a number of points where the reef can safely be crossed. There and on the spit to the west of South Cay the reef does not come as near the surface, that end of the reef being lower both on the north and south side of the atoll.

The entrance to the atoll is on the west side. It is flanked on the north side by Northwest Cay, and by the smaller South Cay about two miles off in a southeasterly direction. The entrance is steep to directly south of Northwest Cay, while a long sunken spit extends from South Cay to the northwest, encroaching upon nearly half the opening to the lagoon. Coral heads are scattered all the way across the entrance, in six to nine fathoms of water; they become quite abundant and luxuriant as we approach the Northwest Cay, and are continued in shallower water on the outer rim of the atoll all the way to the eastern face, seemingly finer and more thriving as they extend to the eastward.

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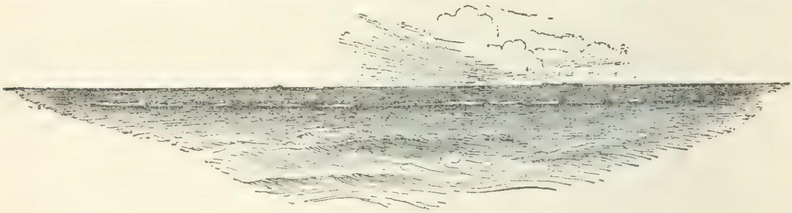
[1] For a list of the West Indian marine algæ, the greater number of which have been collected also at the Bahamas, see G. Dickie, "On the Marine Algæ of Barbadoes," Journ. Linn. Soc., Botany, Vol. XIV. p. 146; and "Contributions to the Botany of H. M. S. Challenger," communicated by Sir J. D. Hooker, "I. On the Marine Algæ of St. Thomas and the Bermudas," Ibid., p. 311.

The same is the case with the heads on the outer face of the southern and eastern face of the atoll; the coral heads increase in size and number as they extend towards the eastern extremity, and take their fullest development on the comparatively broad shelf stretching to the eastward. As far as I could ascertain with the water glass and lead the coral heads do not extend beyond eighteen or nineteen fathoms, but owing to the steepness of the outer slope of the atoll it was difficult to decide this. When we examined the eastern shelf the sea was too rough to enable me to detect the presence of heads beyond seventeen fathoms, and at that depth they were more distant, and frequently separated by large patches of coral sand, while towards the atoll they gradually became more numerous and more thickly crowded, attaining apparently their maximum of development in the belt inside of ten fathoms.

The poverty of the coral fauna of the interior of the lagoon is very striking. As I have stated above, the bottom is nearly level, sloping as seen in the longitudinal section (Plate II. Figs. 2, 4) very gradually from a depth of three fathoms to five and a half fathoms, when the slope increases more rapidly to seven, ten, and then suddenly drops down to over a hundred (140) fathoms. Transverse sections of the atoll show well its gradual deepening as we proceed from the inner eastern edge to the section across it near the western entrance of the lagoon. The floor of the lagoon is of a very uniform depth transversely, as all the sections taken from north to south readily show; but the depth increases as they are taken more to the westward (Plate II. Figs. 5–7), with the exception of one or two small shallower patches, on which some Gorgonians and algæ are growing. On the western face, the coral heads are more developed near the two little islets forming the gate posts as it were to the lagoon. They form a large broad patch, gradually passing on the one hand into the broad ring of scattered coral heads below the 10 fathom line on the western face of the atoll, and on the other hand into the two narrow belts of scattered coral heads and patches of Gorgonians found running along the interior of the lagoon more or less parallel with the shallowest part of the reef. This belt of heads rarely extends to a greater depth than one and a half to two fathoms, and has a width of usually less than one hundred yards, thus leaving the whole interior of the lagoon free from coral heads. Judging from the descriptions of Dana, Darwin, and others of the growth of coral heads in the interior of other lagoons, their absence in a lagoon as open as that of Hogsty Reef seems to be an exception. This is the more remarkable as the position of this atoll is such that from its constant exposure to the action of the prevailing trades a great mass of fresh sea water is constantly poured into the lagoon for more than half its circumference. This mass of water of course washes constantly the scattered heads parallel to the line of least depth, but also throws into the inner lagoon water loaded with particles of sand, which cover its floor and leave apparently no chance for the growth of anything except algæ and corallines in the main basin of the lagoon. It is quite evident, when watching the huge trade wind breakers following one another in rapid succession, that they must act as a very efficient force pump in driving an immense quantity of water to the westward, thus constantly changing the water in the lagoon, and rapidly removing the carbonate of lime it holds both in solution and in suspension.[1] It is only when we reach the western part of the atoll, where the depth increases, that a great part of the water forced into the lagoon by the breakers finds its way out in part through passages both on the north and south faces, but mainly through the wide western entrance of the lagoon. The entrance is nearly a mile wide between the 3 fathom lines of opposite sides, and the section across it shows a greater depth (five, six, and seven fathoms) than at any other section of the lagoon. A strong westerly current is always running out, probably due to the mass of water incessantly piled up by the breakers into the eastern half of the comparatively closed portion of the lagoon.


HOGSTY REEF.

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[1] Murray and Irvine, Proc. Roy. Soc. of Edinburgh, 1889, p. 79.

The action of the water on the bottom of the lagoon is clearly seen in all the patches of clear sand by well defined ripple marks, showing the unstable condition of the sand even at depths of six to seven fathoms.

Owing to the steepness of the edge of the Hogsty bank, the 100 fathom line represents very closely the width of the growing belt of corals. The approximate centre of the inner line of breakers is within one hundred yards of the inner 3 fathom line. I was informed by our pilot that both Northwest and South Cays had increased in size, the former in length on the northerly face, the latter on both its east and west faces. Northwest Cay is mainly built up of the broken fragments of corals thrown up on its northern faces derived from coral heads to the eastward and westward of the cay, and South Cay from the heads growing either on the spit to the northwest or to the eastward on the southern face of the atoll. The cays are nearly flat, with steep shores about fifteen feet high, their surfaces covered with fragments of broken shells and corals, and with here and there small patches of vegetation consisting mainly of the different plants so characteristic of the shore line of the Bahama Islands. On parts of the shores of the cays the recent coral rock forming the underlying base of the islets can be seen sloping seawards. The cays at the time of our visit were occupied by a rookery of boobies.

One cannot fail to be struck with the fact that on Hogsty Reef the most luxurious growth of corals is from a depth of five or six fathoms to ten or twelve, and that below that point, while still flourishing, the heads are not clustered as closely together as in shallower water, while the heads similarly diminish rapidly in number as they reach the line of breakers. Contrary to the observations of Bourne[1] and Hickson, who lay great stress on the growth of corals inside of the lagoons of the atolls they have examined, in our atoll their growth is practically limited to a very narrow belt close to the line of breakers, of not more than one hundred to one hundred and fifty yards from the principal line of the corals awash. The slope from the ring of the atoll to about ten or fifteen fathoms is quite moderate, while beyond that it drops very fast. It is on that edge, as has been observed by others, and as is specially marked everywhere in the Bahamas, that the coral heads flourish best. The ring of coral heads is generally from one hundred and fifty to four hundred yards wide, except at the eastern face, where the width of the reef is nearly a mile and a quarter.

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[1] Bourne states (Proc. Royal Society, March 22, 1888, p. 440) that corals thrive remarkably and most vigorously in that part of the Diego Garcia Atoll which is most remote from the influence of currents, and he attributes to corals a greater capacity as vegetable feeders than has been supposed. But no decayed vegetable masses derived from the shores of the lagoon are found in either of the atolls I have examined, Alacran or Hogsty. In these atolls there is nothing else for the corals to feed upon except what is brought by the currents of the sea.

There is of course nothing to show that the substructure of Hogsty Reef differs in any way from that of the other banks of the Bahamas. It is fair to assume that, like them, it was built up of æolian rocks which have gradually been worn away by the action of the sea, so that between erosion and subsidence nothing has been left to indicate the existence of the former Hogsty land beyond the growth of corals which now flourishes upon the underlying æolian strata, and which they completely cover.

That the corals grow in a more or less circular belt I have attempted to explain by the action of the breakers pounding upon the surface of the bank, thus forming a gigantic pot-hole. Finally the water breaks through this pot-hole on its lee side, forms an opening, and changes it into a lagoon. This explanation of the formation of Hogsty Reef had occurred to me before I had seen the so called Serpulæ Reefs of the Bermudas, of the structure and mode of formation of which I gave a short account in the June number of the American Journal of Science for 1894. I shall in my report on the Bermudas further consider this subject.

## THE COAST OF CUBA.

**Plates I., XIII., XIV., XLI. to XLVII.**

We were fortunate enough, both in going to Santiago de Cuba and in leaving it for Hogsty Reef, to run along the south shore of Cuba, to and from Cape Maysi, in daylight. This gave us an admirable opportunity to obtain an excellent impression of the terraces and the elevated reef extending along that coast, forming so prominent a feature of Cuba at intervals all the way from Cape Cruz to Cape Maysi, and similarly all along the northern coast, past Baracoa, Gibara, Matanzas, Havana, and Mariel. But while we thus obtained an excellent idea of their extent, so superficial an examination could only give me data for the most general conclusions regarding the part these elevated limestones and the reefs had played in the geological history of Cuba, far less for any views regarding their mode of origin.

The white honeycombed limestone cliffs which are so characteristic of the whole coast of Cuba are known locally as "soboruco," the name applied by the natives to the honeycombed limestone rock forming the elevated terraces, though originally applied only to the elevated coral reef forming the first terrace. These terraces are striking features on certain reaches of the coast, and are so noted in the descriptions of the coast pilots that they often serve to distinguish special points.

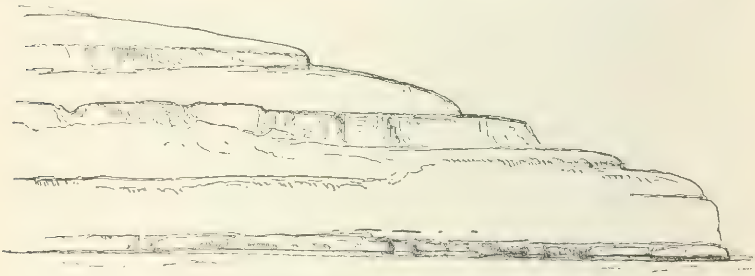
During my trip along the north coast of Cuba I became satisfied that I had misinterpreted the nature of the elevated terraced limestones of the shores of the island. With other naturalists, I had been led to think from a first examination, made many years ago, that these elevated limestones were coral reef rock limestones representing coral reefs of perhaps twelve to fifteen hundred feet in thickness. The true character of the coral reef rock, which has in general been elevated to a height of not more than twenty-five or thirty feet, is readily made out. The exposed surface of the platform of the first terrace is often one mass of coral heads, and it requires but little effort to reconstruct this into a recent living reef. When we come, however, to the flats of the second and third terraces, the problem is not so simple. It is evident that the limestones are of older age than those of the raised coral reefs flanking the shores. They underlie the elevated reefs, and, while greatly altered, yet contain an occasional mass of coral belonging to the reef-building species, but so few in number that we can hardly call the stone of which they form a part a coral reef limestone. These questions were brought to mind vividly at Santiago, while exploring the limestone terraces; also at Saboney, at Baracoa, where the thickness of the elevated reef is not more than thirty-five feet, at Banes, at Matanzas, and at Havana. It became important to determine exactly the age of the limestones forming the second, third, and higher terraces, and to ascertain how far the presence in older limestones of an occasional mass of a species of reef-building coral, at different heights all the way up to two hundred and fifty or even to over four hundred feet from the level of the first terrace, justified the conclusion that these deposits of older limestones belong to the group of coral reef limestones. Such an inference from the presence of a few corals in the older limestones seems to me no more reasonable than to speak of a few isolated heads of reef-building species found along the shore lines of any coast or island as constituting a recent coral reef.

My observations are here given as noted during the cruise of the "Wild Duck." Not having myself the time to make the necessary explorations, I gladly accepted the proposition of Professor Robert T. Hill, of the United States Geological Survey, to carry on this exploration, and to determine the character of the elevated terraced limestones, and their relation to the overlaying elevated coral reef, as well as the greatest altitude to which true coral reef rocks could be traced. His Report will be printed in the Museum Bulletin, and I shall refer to this paper for such illustration as will supplement the observations of Professor Hill.[1]

## Cape Maysi to Santiago de Cuba.

**Plate I.; Plate XIV. Fig. 5; Plate XLVII.**

From the westward of Cape Maysi to Caleta Point there are four very distinct terraces, and signs of a fifth, the summit of the hill forming Caleta Point being probably nearly twelve hundred feet in height. The accompanying sketch will give better than any description of mine an idea of the appearance of the shore as seen from the yacht's deck. As we go westward these terraces become more and more indistinct. They are no longer continuous, as we saw them for a long stretch to the eastward of Caleta Point. There has been great erosive action, and many valleys have been cut from the shore through the limestone hills back to the older formations upon which the shore hills rest. During the erosion, the hills parallel to the coast line have been cut into disconnected patches, and often reduced to a height less than that of the second or third terrace on the shore line near Caleta Point. In the process the lines of the terraces have also frequently been obliterated, so that it is impossible to detect their continuity. Here and there isolated remnants, generally of the third terrace judging from their comparative altitude, can be traced at intervals all along the shore line to Santiago de Cuba. The first terrace formed by the line of the elevated shore reef is most persistent; it can often be traced for miles where the



TERRACES AT CALETA POINT.

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[1] A preliminary note on the Geology of Cuba, by Professor R. T. Hill, will be found in the September number of the American Journal of Science, 1894, p. 196.

existence of the others cannot be detected. The faces of the terraces show the exposed limestone to be greatly honeycombed. It is often columnar in appearance, and large caverns and cavities of all sizes open into the exposed vertical faces of the terraces. Some of the ravines running westward from the shore line expose, in their section of the shore hills, high cliffs of limestone similar in structure to those of the terraces. This is particularly well shown in two of the ravines beyond Caleta Point. Some of the hills near the shore, which as seen from the ship seemed to be limestone, must have reached an elevation of at least eleven or twelve hundred feet. To the west of Jauco River the hills in the rear rise to at least sixteen or perhaps eighteen hundred feet, but no shore limestone hills could be detected of a probable height greater than one thousand to twelve hundred feet, judging from the exposures visible in the ravines.

Near Imia Bay another great ravine has cut through the coast range limestone hills. The second terrace is obliterated by the talus of the third terrace, and the hill behind this rises to about the height of the fourth terrace. This part of the coast must have jutted out somewhat, and that portion of the shore which formerly formed the first and second terraces has been washed into the sea, and left only the steep cliffs forming the base of the third terrace, which was further inland.

Between Sabana la Mar and Baitiqueri there are traces of the second terrace, the third terrace is specially well marked, and indications perhaps of the fourth are visible near the summit of the shore hill.

To the eastward of Port Escondido the shore hills show the lines of at least four of the terraces. But the breaks in continuity of the terraces due to the elevation of the coast are, as I have stated, very numerous, and by far the greater mass of the shore limestone hills must have been carried into the sea. Formerly their characteristic terraces undoubtedly extended at intervals, if not continuously, all along the southern shore, and probably were as well marked as we have seen them to the eastward near Caleta Point.

When we come to the entrance of the harbor of Guantanamo, the shore hills show still more plainly the effects of the great erosion which has taken place all along the southern coast. We find this erosion to be greater in proportion as we go northwestward from Cape Maysi. To the westward of the harbor of Guantanamo we have fragments of the first and second terraces. To the east of the harbor the shore is flanked by low more or less conical hills, which from their shape completely conceal the terraces of which they are only the remnants.

From Guantanamo the shore hills are not terraced, and to the eastward of Hatibonico the first shore terrace again becomes prominent. From the pier to the westward of Morillo Chico the shore limestone hills are again seen. They rise there to six hundred or eight hundred feet perhaps, and behind and above them are seen the dioritic mountains upon the flanks of which the shore limestone ranges have been deposited and have been raised during the periods of elevation. Near Baitiqueri River an isolated shore limestone hill shows plainly four terraces.

Guantanamo (Plate XIV. Fig. 5), like Santiago de Cuba and Port Escondido, is a flask-shaped harbor which has been formed by erosion in the limestone during the elevation of the belt which flanks the whole of the southern shore of Cuba from Cape Maysi to Cape Cruz. The same formation is said to extend to Cape San Antonio from Cape Cruz. Its limits on the south shore are not known to me, but I have followed it from Cape Maysi to Cape San Antonio on the north shore. The harbors of the north shore from Baracoa to Bahia Honda, like Livisa, Banes (Plate XIV. Fig. 6), Padre (Plate XIV. Fig. 7), Nuevitas, Matanzas, Havana, and others of a similar character, have all been formed by the erosion of their drainage area across the shore limestone hills during the rising of the shore line.

## Santiago to Saboney.

During a trip we made to the Juragua iron mines I was able to examine more in detail a considerable stretch of the shore limestone hills and of the elevated reef. The narrow gage railroad which runs from the dock of the company in the harbor of Santiago de Cuba rises rapidly upon the hills which surround the bay, and attains a height of about two hundred and fifty feet. It then drops gradually to the shore, and runs for a distance of about ten miles, to Saboney, along the shore line, keeping all the way on the top of the first terrace, the surface of the elevated reef. At the greatest height reached by the railroad behind Santiago, in the cut about three kilometers from the company's wharf, we found a number of fossil shells, embedded in a sort of marl formed of the decomposed limestone of which all the exposures of the hills consist. So much is this the character of the limestone in the vicinity of the harbor of Santiago that nowhere except in some of the cuts to the eastward of the city, and after passing over the sea face of the hills, are we able to obtain characteristic specimens of the limestone rock of the shore hills.

According to Mr. Dall, who has been kind enough to examine these fossils, they "are of old Miocene age, the same as the age of Bowden in Jamaica and those of the Isthmus of Panama. They are also represented in Florida by what has been called the Chipola epoch, to which the beds of Ballast Point, Tampa Bay, belong. Some of them appear identical with fossils from the Chipola River, Florida. Fossils of the same age were obtained on the Cuban coast by Professor R. T. Hill and Dr. J. W. Spencer at various points."

After passing the summit and descending to a point a hundred and sixty feet above the level of the sea, we came upon a cut in the road, where we found hard limestone and a small isolated head of a fine Astræa, but no coral rock. From there down, the rock is hard limestone greatly honeycombed, as are all the faces of the terraces along the coast parallel to which the railroad runs. The first terrace, upon which the railroad runs, is about twenty feet above the level of the sea. It is nowhere more than three hundred feet wide, and forms an ideal railroad bed. At Saboney the road enters into a gap of the shore hills and soon passes out of the region of the limestone shore hills to meet the dioritic rocks which compose the second range of mountains. At the gap of Saboney, and thence to the westward, the second and third terraces are very prominent. The second terrace is about fifty feet above the first, and the third not more than sixty feet above that. The third terrace is often obliterated by erosion. The first terrace in spots has been carried away by the sea, and cliffs have been formed which reach the height of the second or even of the third terrace.

We were indebted to the courtesy of Mr. Shuman, the agent of the Juragua mines, for an excellent opportunity to examine a part of this elevated coral reef, forming the surface of the first terrace at Saboney, — the old surface of the shore reef. We made good collections of specimens of Mæandrinæ, two species of Astræans, a large Colpophyllia, and a fine Allopora, all belonging to species now found living.[1] The corals were clustered very closely, much as they would now be found growing on a living coral reef, and quite as thickly packed.

The examination of the terraces along the line of the Juragua Railroad shows plainly that the vertical distance between the second and third terraces, not being more than fifty to sixty feet, is not of greater height than the depth at which corals would readily grow up from a new base. The flat surface which forms the upper part of the elevated reef, the first terrace, is covered with several species of corals apparently killed *in situ* by the gradual elevation of the base upon which they were growing, and of which they formed the living top at the time the elevation began. The lower portions of the reef have grown up at greater depths, and, as they died or were covered by more flourishing or by growing corals, have formed the base upon which the newer crop built their way little by little to the surface. The terraces as we see them form a series of steps, each of considerable width, so that the fifth terrace, for instance, might be fully twelve to fifteen hundred feet horizontally removed from the shore line. Of course the first terrace may have been much wider than where I measured it, and much of its sea face may have been worn away. Still, as the depth off the south shore of Cuba is very great, and the limit of coral reef builders is at almost every point of the coast reached within a comparatively short distance, it is not probable that the width of the first terrace was very considerable. The examination which I made does not settle the question that each of the terraces corresponds to a separate growth of corals laterally; it neither proves or disproves the former continuity of the coral reef, nor its division through the agency of the waves into perhaps one or more distinct terraces. I can only say that the character of the rock exposed on the faces of the second and third terraces showed quite plainly that they consisted of older rocks with very marked differences, — differences which would indicate a greater age in the face of the second terrace than in the first, and a still greater age in the third, but not necessarily, as the terraces may have been cut successively in limestone of the same age. The condition of the fossil corals was specially marked, and the differences noted in fossilization quite agreed with the different conditions of the limestones of the second and third terraces as contrasted with each other, or as compared with that of the first and youngest elevated coral reef terrace. We may conclude that at Saboney at least the first terrace only is composed of an elevated coral reef, while the limestones of the second and third terraces are much older, and, although containing a few corals, yet are not coral reef limestones.

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[1] The species of corals characteristic of the elevated reef (the "soboruco") belong to the following genera: Colpophyllia, Orbicella, Porites, Mæandrina, Agaricia, Favia, Stephanocœnia, Manicina, Madrepora, Isophyllia, and Siderastrea; wherever thus far collected in the Caribbean, they all belong to recent species of reef builders characteristic of the West Indian fauna.

It may be that the isolated corals identical in species with those now living or with those of the elevated reef forming the first terrace, which are found on the second and third terraces near Santiago, at Baracoa, and to heights of nearly five hundred feet near Banes, are the remnants of the former extension of the veneer of coral reef which covered the shore of Cuba during the time of elevation of each terrace; that is, there probably existed at the time when the older terraces were formed a fringing reef, much like the present elevated fringing reef forming the first terrace, each reef corresponding to its terrace and forming on the sea face of the older underlying limestones a veneer of about the thickness of the present "soboruco" reef, say twenty-five to thirty feet. The patches or isolated heads upon the faces of the older limestones are probably the remnant of these successive reefs, the one upon the first terrace being the youngest. The existence of these scattered patches has led many observers to assume that the elevated limestones are of the same age as the elevated reef (the first terrace).

The sheet of coral, which may have extended to a height of nearly five hundred feet along some parts of the Cuban shore, has been eroded and swept away by the same agencies which have formed the peculiarly shaped limestone hills of the shore line. This erosion has been very extensive; with the exception of the first terrace, where the coral reef is nearly continuous, it has left only an occasional patch of coral reef or an isolated head here and there, at varying altitudes, to testify to the former existence of the coral reef sheet, the higher inland parts of the reef having all been eroded from the sides of the underlying older tertiary rocks. Yet it is strange that no patch of recent reef rock of any extent should have been met with thus far, unless we except the elevated reef of Matanzas, where, according to Professor Hill, it reaches a height at least of a hundred feet.

A similar coral sheet, resting upon oceanic beds and the so called Scotland beds, has been carefully described by Harrison and Jukes-Browne[1] as extending at the Barbados from the sea level to nearly eleven hundred feet. This sheet consists of a series of "platforms built up one around the other as the island slowly rose from the sea," and this I imagine to have been the case with the successive elevated reefs of the Cuban coast. The erosion at the Barbados seems to have been much less than along the Cuban coast, leaving the bases of the successive platforms of coral reef continuous. According to Browne and Harrison,[2] there are six distinct terraces between the sea level and a height of five hundred feet, and between that height and one thousand feet they indicate at least five additional terraces. They say that there are not many places where the thickness of the coral rock is greater than two hundred feet. In some places it appears to reach two hundred and thirty feet, and in one place two hundred and sixty feet.

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[1] The Geology of Barbados, by J. B. Harrison and A. J. Jukes-Browne. Published by Authority of the Barbadian Legislature, 1890.

[2] The Geology of Barbados, by A. J. Jukes-Browne and J. B. Harrison. Quart. Journ. Geol. Soc., XLVII. 197.

Guppy[1] describes the elevated reefs of the Solomon Islands, where extensive degradation of the surface has also taken place, as being of very moderate thickness. This agrees with the structure and thickness of the elevated reefs of Barbados and of Cuba, as I imagine them to have been.

Professor Dana says: "The atoll of the Tortugas, and others in the West Indies, are regarded by Mr. Agassiz as having a basement up to the coral growing limit of pelagic limestone or of some other material. It may be so; but there is as yet no proof of it."[2] Surely the extension of the miocene rocks of the peninsula of Florida south under the district of the belt where coral reefs are found may fairly be assumed. The existence of the modern limestone of the Pourtalès Plateau has been proved by dredging to run close to the seaward limit of the coral reefs. The Alacran atoll, as well as all the coral reefs of the Yucatan Plateau, are underlain by a marine basement (not composed of corals), into the extension of which one can penetrate nearly three hundred feet in depth. And, finally, the recent explorations of Professor Hill and myself along the northern coast of Cuba have proved beyond doubt the existence of a miocene basement underlying the elevated coral reefs.

While not denying that subsidence is necessary to account in many cases for the formation of deep lagoons and deep channels, it must be left to others to prove that these depressions and channels have been cut through the thickness of the coral reefs, and not through that of the basement. It is quite possible to imagine lagoons to be formed hereafter in some of the Bahamas and in the Bermudas by subsidence, which might have a depth of nearly sixty fathoms and yet have a thickness of corals of not more than a few feet on the upper margin, extending along the inner and outer slopes to a depth of not more than twelve or fifteen fathoms.

The vertical distance between the lower terraces near Saboney was far less than between those observed at Caleta Point. It is quite possible that at the eastern extremity of the island the terraces which are still so plainly marked are not the only terraces once existing. The erosion which made, as we have seen, such great changes in the physical aspect of the shore line to the west may also have acted there to a less extent, but perhaps quite enough to have obliterated the lines of some of the terraces intermediate between those which at Caleta Point have been designated as one to five. From the Juragua mines one gets an excellent distant view of the shore limestone hills stretching to the west and east, and well separated from the inner range which forms a part of the mass of Gran Piedra. At Saboney, and at several places on the way from Santiago along the outside of the line of the railroad, small boat harbors have been formed on a diminutive scale by erosion, very similar to the larger ones so characteristic of the Cuban coast, and of which Guantanamo (Plate XIV. Fig. 5) and Santiago are the two finest examples on the southern coast. Many bights on the coast have been produced in a similar way. Neither at Santiago nor at Guantanamo do we find any trace of terraces along the sides of the eroded limestone hills which surround these harbors. They have been obliterated by the wash along their sides into the drainage basin fringing the bays. On our way east from Santiago we so timed our start as to see by daylight that part of the coast near Santiago which we had passed after dark. To the westward of the entrance of Santiago the terraces are most indistinct, the third terrace being alone fairly defined, while to the eastward a fine line of terraces can be seen from the sea. We were able to get a distant view of the second and third terraces running along the hill slopes above the first terrace, forming the road-bed of the railroad leading from Santiago to Saboney. Through the gap at Saboney we could see the line of the Juragua mines on the foothills of the Gran Piedra. To the eastward of the Saboney Gap, before reaching the pier of the Spanish American Mining Company, one of the foothills shows four terraces quite plainly, the same number which on our way to Santiago we had seen on the isolated hill near Baitiqueri River.

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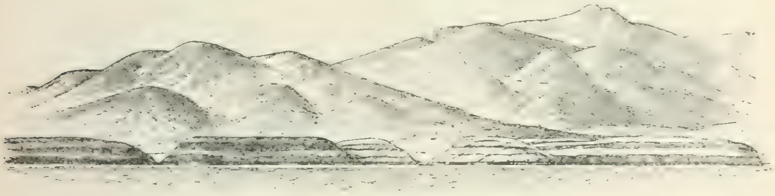
[1] The Solomon Islands, by H. P. Guppy. London, 1887.

[2] Corals and Coral Islands, p. 292.

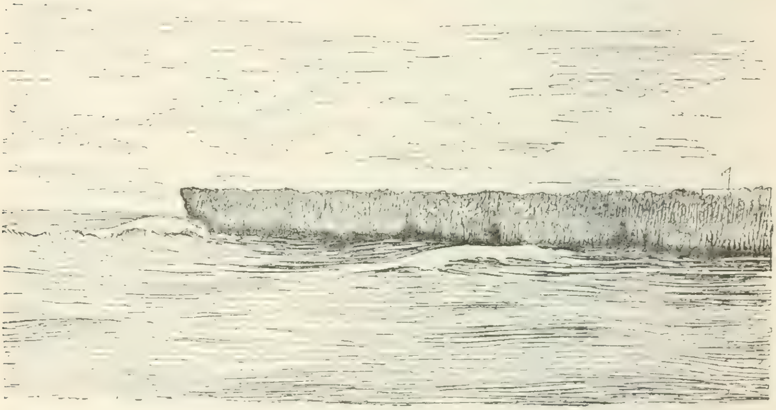


GRAN PIEDRA AND TERRACES NEAR SABONEY.

## Baracoa to Banes.

**Plate I.; Plate XIV. Figs. 3, 6; Plate XLI.**

We reconnoitred the north shore of Cuba from Baracoa to Havana, reaching the former place from Ragged Island. Baracoa is a small harbor, eroded out of the first terrace in a gap of the shore hills caused by the drainage of the country behind it (Plate XIV. Fig. 3). The entrance is narrow, flanked on either side by well worn and honeycombed reef rocks. To the south of the entrance the platform of the first terrace extends for nearly a mile, and upon the inner edge, at the foot of the cliffs of the second terrace, around Miel Bay, the town of Baracoa is situated. The second and third terraces can be seen plainly, and the small fort which commands the harbor is built upon the second terrace. Traces of the third terrace can also be seen on the hill to the north of the entrance to the harbor. A river is banked off from the bay by a beach thrown up by surf, so that it does not empty directly into the bay, but runs parallel with the shore for the greater part of its circumference, emptying finally into the southeast corner of the port, where it is protected from the swell of the sea.



ELEVATED REEF (SOBORUCO), ENTRANCE OF BARACOA.

The first terrace of the elevated reef of Baracoa presented the same features which had so greatly interested us when examining the reef at Saboney. We found huge masses of Astræans, of Mæandrinæ, of Madrepores, of Allopora, apparently all in place as they grew, and likewise we found in the section of the terrace on the harbor side the same species of corals composing the bulk of the reef rock. On going up to the flat of the second terrace, we found isolated masses of corals and shells, which evidently form a considerable part of the limestone of the cliff extending from the first to the second terrace. To the south of the fort one can reach the base of the cliffs of the third terrace, in which we found again isolated corals of species characterizing the limestone of the second terrace. On the second terrace we found considerable red earth. The whole thickness of the first terrace of the elevated reef at Baracoa, of not more than thirty-five to forty feet, wherever there was a section showing its character, proved to be one mass of heads of corals closely packed together, — huge masses of Astræans, of Allopora, of Mæandrinæ, etc., all cemented together just as they must have grown on the surface of the reef when it was living.

Not more than five miles from us in a straight line rose Yunque, an elevated mass of limestone underlaid, according to Professor O. W. Crosby, by older metamorphic rocks, and stated by him to be one continuous mass of solid reef rock,[1] the upper part perhaps being of a greater age than the lower limestone cliffs. Unfortunately the condition of the roads was such as to make it impossible for us to reach the mountain, which I was most anxious to visit in order to ascertain whether in this great mass of limestone any trace of the successive terraces of the coast reefs could be found. Judging from what could be seen of the base of the mountain from the sea, the talus at its foot, built up of the disintegrated limestone which for years has been falling from the upper layers, must make it wellnigh impossible to ascertain the thickness of the successive terraces which compose the Yunque. Still more difficult would it be to determine their number, and whether they were caused by the erosive action of the sea or were built out successively seaward during the different periods of elevation which must have followed one another with (geologically) considerable rapidity in order to bring about such a succession of terraces as can still be recognized to the south of Baracoa. The apparent columnar structure of the flanks of Yunque, especially as they approach the summit, due to the breaking away of huge masses of limestone, gives no great hope that we shall ever be able to make out the history and succession of the terraces of which this mass of limestone is the monument (Plate XLI.).

Passing to the westward, the ranges of shore hills show markedly the effect of the extensive erosion to which they have been subjected. The terraces become indistinct after we pass the first point beyond Baracoa. The vegetation is very dense, and nothing can be seen from the sea indicating the successive lines of former elevation. But the shape of the hills — worn into saddles, into peaks, into isolated cones, forming indistinct ranges more or less parallel to the coast — sufficiently shows how great has been the effect of the erosion on the limestone hills. Between Baracoa and Mangle Point the whole country is broken up into disconnected bits of hills, those nearest the shore being from six hundred to nine hundred feet high. A careful study of the cross breaks of the shore hills might reveal some limestone faces, and throw light on the age and succession of the limestone belt which covers so great a part of the coast of Cuba from Baracoa to Cape San Antonio. Here and there along the coast we may recognize — as, for instance, near the Saddle of Bay, in the range of hills nearest the shore — the second and third terraces. To the west of the Sierra de Moa, near Cayo Grande de Moa, begins a series of saddles and peaks culminating in the Cuchillas del Pinal, which seem, as seen from the sea, a series of gigantic ant-heaps and disconnected saddle-like ridges, showing the great effect of erosion in this district. We could see the eroded shore hills flanking the Sierra de Cristal, and the low shore extending past the ports of Cabonico, Livisa, and Nipe, all fine examples of the flask-shaped harbors of Cuba. To the eastward of Livisa indistinct traces of the third terrace could be seen.

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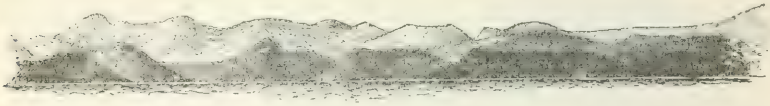
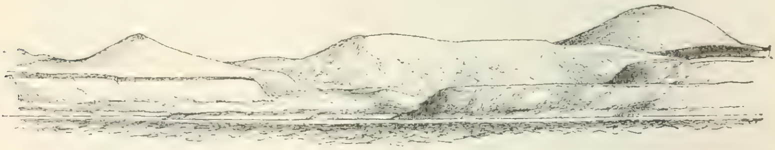
[1] Professor Hill in his report to me distinctly states that the Yunque limestone is not a coral reef limestone.



CUCHILLAS DEL PINAL.



TERRACES AND ENTRANCE TO NIPE.

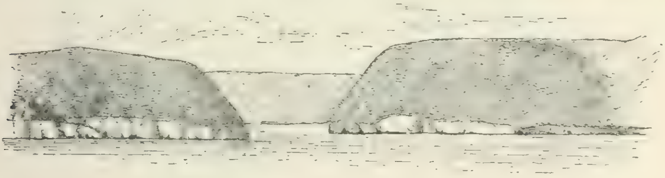
It was not till we faced the entrance to Nipe that we once more clearly traced in the spit to the westward the first, second, and third terraces. To the eastward of the entrance the second terrace was well defined.

## Banes to Padre.

**Plate I.; Plate XIV. Figs. 6 and 7.**

On each side of the entrance to Banes the second terrace could be seen, towards Mulas Point the third can be indistinctly followed for a considerable stretch, and towards the Sama hills there appear to be four, if not five terraces. The winding cañon forming the entrance to Banes is a fine example of the passages, more or less tortuous, leading into the flask-shaped harbors so characteristic of the Cuban coast, — harbors due to the gradual cutting away of the drainage area of which they are the sinks during the elevation of the coast. From the wharf of the banana plantation of the Messrs. Dubois we went inland to the village, to a height of fifty-five meters above the level of the sea and a distance of six kilometers, passing through a region of limestone similar in structure to that of the rocks through which the cañon forming the entrance of Banes had been cut. We drove up to the summit of a hill about eighty-eight meters higher than the village, say one hundred and forty-three meters above the level of the sea. The top of this hill was probably a part of the fourth terrace. We found on its highest ridge, forming a nearly level saddle, a species of Astræa *in situ*. The rock in place here, and lower along the slope of the hill, is everywhere the same limestone, greatly disintegrated, so that the lines of the terraces are nearly everywhere obliterated.

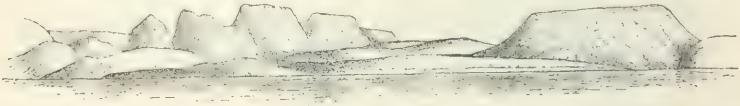
Having become acquainted with the entrance to Banes (Plate XIV. Fig. 6), we had, on leaving the port, an excellent opportunity to see the cañon through which we passed out, and to note the deep cuts, from seventy-five to one hundred feet in height, forming the nearly vertical sides of the main channel. The channel carries from four to six fathoms, is long enough and tortuous enough to make a perfectly landlocked harbor, which opens out after a little over a mile into a broad bay with deep water, from five to six fathoms, close to the shore. The



OUTLET OF PORT BANES.

shores of the bay are low, consisting mainly of decomposed limestone and of red earth, making an exceedingly fertile soil. Harbors like Nipe, Banes, Padre, and the like, which are so common on the north coast of Cuba, were of little use before the days of steamers. Their entrances, facing the full force of the prevailing trades, make it nearly impossible for a sailing craft to weather the shores and get an offing. It was simple enough to sail in, to tack out against the trades was quite another matter.

After passing Point Lucrecia four terraces can be distinguished between it and Point Sama, but owing to the extensive denudation and erosion of the district only isolated parts of the several terraces are left, and it is often difficult to determine to which terrace they belong. Port Sama is an indentation formed by a break in the shore hills. To the westward of the port a long ridge extends, at the extremity of which the four terraces composing it stand out very clearly; and here we have an excellent guide for the determination of the terrace to which the isolated saddles of the country both east and west belong. We then come upon a stretch of shore eastward of Naranjo crowded with isolated saddles and peaks, giving a peculiar aspect to that part of the coast. All the way to Gibara the shore hills are eroded into the most fantastic shapes, leaving no trace of any of the higher terraces. Thus the limestone hills appear from the sea to be one continuous mass from the base to the summit. A careful examination of the slopes and valleys would however probably reveal in favorable localities the lines of the old terraces. To the westward of Gibara the high limestone hills, so characteristic of the shore line all the way from Baracoa to Gibara, recede from the coast, and we now only find low shore hills, the highest point of which can scarcely be as high as the fourth terrace.



LIMESTONE HILLS BACK OF NARANJO.

The coast as seen from the sea is now low as far as Sagua la Grande, where the Sierra Morenas approaches the coast again. The spurs of the main range which receded from the coast westward of Gibara are again within sight from the sea, and continue to form the principal part of the background of the shore line past Cardenas and Matanzas, and well towards Havana.

## Padre to Nuevitas.

**Plate I.; Plate XIII. Fig. 1; Plate XIV. Fig. 7.**

The entrance to Padre is very wide, fully a third of a mile. It is straight, and has all the appearance of being the mouth of a great river. After about two miles it opens into a Y-shaped channel formed by islands lying opposite its western end, and then spreads into a bay (Plate XIV. Fig. 7). The shores behind the beaches are low, and wherever there are any rock exposures the same reef rock is found which occurs all along the coast, and the same limestone half-way up the low hills to the westward of the town. There is a great deal of red earth, and the soil is very rich.

The shores on both sides of the channel are flanked with low mangrove islands. We find here the beginning of the extensive system of cays which runs uninterruptedly from Nuevitas to Cardenas; but to the south of Nuevitas the channel which separates the cays from the mainland is not as yet cut through the space separating consecutive harbors to the north of Padre. With little more erosion the condition of things existing to the north of Nuevitas would be extended as far as Padre. To the westward of Padre are a number of low mangrove islands within the reef which extends from the western side of the entrance. South of Padre an extensive reef with coral heads awash extends from Herradura Point to the entrance of the harbor. The shore line of the first terrace is now frequently obliterated by the sand formed from the débris of the reef outside and constantly thrown against the shores by the prevailing winds. The remnants of the second and third terraces form the hills west of Manati, which may be about two hundred feet in height, and are the only high land in this vicinity.

## The Cays from Nuevitas to Cardenas.

**Plate I.; Plate XIII. Figs. 1 to 5; Plate XIV. Figs. 1, 2.**

The entrance to Nuevitas is very similar to that of Padre. A coral reef has formed a prominent spit to the south of the entrance, enclosing a shallow lagoon open to the north. Such elongated patches or spits, like the reef at Padre, are found all the way from Mangle Point, and north of Nuevitas they form a nearly continuous living reef to the westward outside of the cays, with here and there a break or passage for boats and shallow draft vessels. After passing Nuevitas the clusters of gulf-weed became more and more numerous.

The long, low cays which extend westward beyond Maternillos Point are separated from the shore by a shallow lagoon, forming a continuous passage for small boats between them and the mainland all the way to Cardenas. The highest point on any of the cays is on Cay Romano, the hills on the northern extremity of which are marked on the charts as being about two hundred and thirty feet high. The monotony of this low shore along which we skirted after passing Maternillos Light was relieved by the hills of Cay Guajaba, ninety feet in height perhaps.

While we could make out the reef rock of the immediate shore line of Cay Sabinal, Cay Guajaba, and Cay Romano, we could also see how great a part of the beaches concealing it was made up of sand formed from the decomposition both of the soboruco and the fragments of the outlying living coral reef. After passing Boca Guajaba, the plateau to the eastward of Cay Romano widens greatly, and upon its eastern edge are Cay Verde, Cay Confites, Cay Cruz, Caiman and Anton Cays, and Paredon Grande, which must undoubtedly once have formed a part of Cay Romano, but have been separated from it by the extensive erosion which has taken place all along this coast, and which has swept away between Nuevitas and Cardenas nearly all traces of the second and third terraces, and perhaps others, and in the majority of the cays has reduced the area once occupied by them even below the level of the first terrace.

## Cay Confites.

**Plate I.; Plate XIII. Fig. 2; Plate XIV. Fig. 2.**

The rock of which Cay Confites is composed showed this clearly. We anchored for the night to the westward of the cay, and had an opportunity of examining its structure. It is on the very edge of the Old Bahama Channel, holding to it on the west very much the same relation which Cay Lobos holds to it on the east. Those parts of the cay not hidden by sand are all made up of coral reef rock of the first terrace. We collected here, as we had at so many other places, specimens of Astræa, Mæandrina, and Madrepora identical with those collected at Baracoa from the reef rock of the first terrace. Between the spits of the older reef rock were stratified beaches of coral sand dipping to the sea, and formed from the débris of the living reef spit extending to the south of Cay Confites, parallel to the edge of the Old Bahama Channel. On the beaches were thrown up some of the largest specimens of Madrepora palmata I have seen. The branches were from twenty to twenty-eight inches wide, fully eighteen inches thick, and some of the pieces were as long as eight feet, and many were over six.[1]

Cay Confites is just on the edge of the bank (Plate XIV. Fig. 2). The northern end of its slope off the cay is steep, leaving no space for an extended reef. The cay is situated at the narrowest part of the Old Bahama Channel, where the trade wind drives into a deep funnel all that comes floating along the equatorial drift from the northern shores of the larger West India Islands and from the Virgin and Windward Islands, so that, besides the blocks of recent corals thrown up by heavy surf on the surface of the cay, there are found logs and twigs of all sizes and of many species of wood, beans, calabashes, sugar-cane, bamboo, and cocoanuts. With a fertile soil many of the waifs thus thrown upon this island would soon get a foothold, and it would be interesting to make a list of the species of plants which are thus carried by the trades and the currents far from their origin. On the poor soil so characteristic of all reef rock land we found growing mainly such plants as are characteristic of the immediate shore line in the Bahamas and other West India Islands. The Pupa so common on the Bahamas was also found on Cay Confites.

## Cay Lobos.

**Plate I.**

Cay Lobos, on the opposite side of the old Bahama Channel, is a recent coral island, at least the exposed surface was entirely made up of fragments of recent corals which conceal the foundation æolian rock upon which the lighthouse has been built.

## Paredon Grande to Cay Frances.

**Plate I.; Plate XIII. Fig. 2.**

The island of Paredon Grande is composed of low, rocky bluffs, remaining from the disintegration of the second terrace, the sea front of which in many places is changed into extensive sand beaches. On the mainland in the distance can be seen the outline of Mount Gunagua. After passing Cay Coco, which only at Coco Point rises above the first terrace, we sailed along a series of disconnected patches of reef rock, the remnants of larger cays undoubtedly, like Cay Coco, Paredon Grande, and the like. Along the face of Cay Guillermo are here and there short stretches of low cliffs, parts of the first terrace, separated by low rounded hills. The low hills of Triguano Island are now faintly seen in the background. The plateau formed by the system of low cays we are describing is widest in the region from Cay Verde to Cay Frances. The terraces here were probably of great width, as the hills of older rocks upon which they flank do not in this part of Cuba come near the coast line, as is the case from Santiago to Cape Maysi, and as far west as Gibara.

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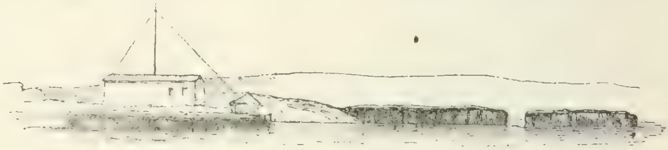
[1] On Enderbury's Island similar large Madrepores with the mode of growth of M. palmata extend over areas of twelve to fifteen feet in diameter. These vie in size with the huge masses of Porites one meets with on the reef flat near Honolulu. They are nearly as large as those found in the rock of the inner reef of Tongatabu, stated by Dana (Corals and Coral Islands, p. 186) to measure twenty-five feet in diameter, or as the Astræans and Mæandrinæ both there and at the Feejees measuring from twelve to fifteen feet (Ibid., p. 146).



PATCHES OF SOBORUCO, CAY FRANCES.

On the cays to the eastward of Santa Maria Cay, as far as Cay Frances, the reef rock cliffs are separated by sandy beaches, and the hills are so eroded that it is impossible to determine the terraces of which they once formed a part. Upon the outer edge of the plateau, in from four to ten fathoms of water, an extensive nearly unbroken reef runs from Nuevitas to Cardenas, and is the source from which are formed the long sand beaches that reach between the low cliffs of reef rock forming the sea faces of the line of cays. There are patches of living corals often extending close to low-water mark, with heads awash at low tide. From these sand beaches, exposed to the full force of the trade winds, patches of recent æolian rock have occasionally formed on this line of cays. Such a patch was observed at Cay Frances. The inner cays, many of them extending toward the shores of the mainland, are composed of limestone, and have been washed away below the level of the sea and converted into regular mangrove islands. Cay Frances is really the first break admitting vessels of any depth inside the cay reef plateau, and forming a channel leading to the main passage running parallel to the coast. Between this and Sagua there are two others, the principal and deepest one leading to Sagua la Grande.

The Fragoso Cays are low, and protected on the face of the inner channel by innumerable small cays. Here and there we find cays with a low reef rock bluff or point, but generally they are bordered by sand beaches. Passing Tocinero Point, we come to a wide bay, a passage for small boats making for the mainland, and soon opened upon the mainland an isolated saddle similar to those so frequently seen farther to the eastward, the remnant probably of limestones belonging to the third terrace.

To the eastward of Vela Cay there is also a wide passage, leading from the outside of the cays to the interior channel along the main shore of the island. We next come to the Lanzanillo Channel, a similar break between the outer cays. To the westward of this extend Lanzanillo Cay, the Jutias Cays, Cay Cañete, and Cay Cristo, separated by the Boca de Marillanes. All these low cays are eroded parts of the second terrace, with low reef rock bluffs separated here and there by long stretches of coral sand beaches derived from the outlying living reefs of the edge of the shore plateau.

## Sagua la Grande.

**Plate I.; Plate XIII. Fig. 4; Plate XIV. Fig. 1.**

We now reach the entrance to Sagua, a wide channel not less than eleven miles long, carrying nineteen feet of water, fringed on all sides with low mangrove islands. To the northwest of the anchorage opposite the town stretches out a wide, shallow bay, the outer edge of which is protected by the continuation of the numerous cays on the north of the entrance to Sagua (Plate XIII. Fig. 4; Plate XIV. Fig. 1). In the distance behind Sagua rise the Sierra Morenas, and to the eastward the Lomas de Sagua la Grande. Sagua is built on piles on the highest part of a mangrove island, which can hardly be called a part of the mainland. A causeway of limestone brought from the neighboring highlands forms the main street and the sidings of the railroad station. To the westward of Sagua and of Bahia de Cadiz extends an archipelago of low mangrove cays, reaching to the entrance of Cardenas Bay (Plate XIII. Fig. 4). Cay Piedras, the most westerly of the islands on the Nuevitas-Cardenas plateau, shows a ledge of low bluffs of the usual reef rock. In the background of the cays the Limonar range becomes a prominent feature of the landscape. The hills approach the shore of the mainland again, and we soon make out indistinct traces of some of the higher terraces in the horizontal lines of the saddle-like hills seen in the distance. To the eastward the Pan de Matanzas rises above the horizon, and the hills which surround it to the eastward and westward make part of the shore line itself. The Bay of Cardenas is easily entered, and we anchored close to the town. There is no rock in place at Cardenas, but the rocks brought for building purposes from the neighborhood are older limestones. All the way east from Cardenas to the inner southern extremity of Cay Romano there is an excellent water way for small boats. The inland navigation is protected the whole way by an almost unbroken line of cays. The distance between the outer cays and the cays forming part of the immediate shore of the mainland is often considerable, though the depth of water is not great. This wide inland sea-way, and also the channels separating the cays on the wider passages, like Boca de Cañete, Boca de Marcos, the entrances to Buenavista Bay, Cardenas, Sagua, Caybarien, and others, are undoubtedly due to mechanical agency. The rock washed by the greater or smaller waves of the outer sea or of the inner bays is readily changed to sand, and thus great stretches of the low cays are converted into flats, and the finer particles washed away, increasing little by little the depth of the water upon them; the currents deepen the channels between the cays, or form the still deeper passages, giving egress to much of the disintegrated reef rock.

## Cardenas to Matanzas.

**Plate I.; Plate XIII. Fig. 4.**

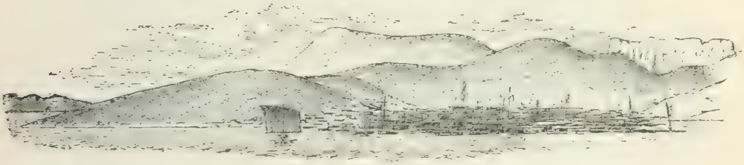
The peninsula of Icacos, which forms the western protection of the harbor of Cardenas, is low, fairly wooded in parts, and opposite Diana Cay there is a fine cliff of older limestones; other outcroppings occur also on the peninsula, farther out from Cardenas, and nearer its eastern point.

After rounding Cay Piedras and passing Monito Cay we followed the low coast making the continuation of the peninsula of Icacos and stretching toward Matanzas. This is flanked on the sea face by low reef rock cliffs, which become higher as we proceed westward; behind them rise a low range of well rounded limestone hills, perhaps two to three hundred feet in height. In the background, to the eastward, the Limonar range passes into the Santa Clara hills, and they in their turn are connected by a low range of hills (the Camarioca Paps) with the Pan de Matanzas lying to the westward of the entrance to the Bay of Matanzas.

## Matanzas.

**Plates I., XLII., and XLIII.**

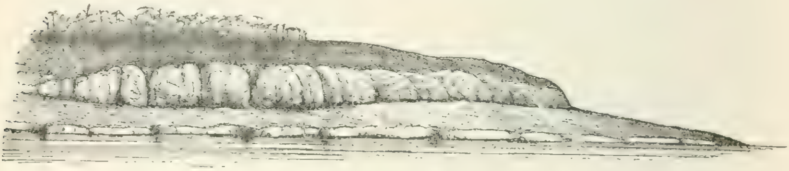
As one approaches the entrance of Matanzas harbor the eroded hills gradually pass into distinct terraces to the eastward of the mouth of the bay. The low elevated coral reef forming the first terrace comes into prominence, and next the line of the second can be distinctly traced, while on the opposite shore near Sabanilla Point three of the terraces are plainly marked. A part of the Bay of Matanzas and the Yumuri Valley have undoubtedly been formed by erosion during the elevation of the surrounding country. The extent of this erosion is seen on all sides of Matanzas, from the terraces of the eastern and western sides of the harbor to the gently sloping hills rising to Bellamar, or to the conical paps of Camarioca, or to the rolling foothills rising to the massive Pan de Matanzas, or to the vertical limestone cliffs nearly as high as the Pan itself to the westward of it. The caves of Bellamar are the finest examples of the many caverns found in the limestone district of Cuba. Their opening is on a comparatively level plateau from three hundred and fifty to four hundred feet above the harbor; but to which one of the terraces the plateau corresponds it is difficult to say. With the exception of the terrace (perhaps the second) indicated in the railroad cutting as we ascend from the bay, there are no traces of other terraces. A few isolated corals are found on the level of the entrance to the caves. The first terrace follows the line of the road, which runs round the bay on the east side. At all cuts of the first terrace we find several species of corals, apparently in place in the reef rock. From Montserrat one gets a beautiful view of the Yumuri Valley. I found no corals anywhere in the limestone on the way up, but a good many shells are embedded in the limestone at an elevation of four hundred to four hundred and fifty feet. The wide valley of Yumuri, with its terraces to the north, is shut in by low ranges of hills, which are cut through immediately back of



PAN DE MATANZAS.

Matanzas by a deep gorge. This gorge must at one time have been the entrance to a flask-shaped harbor very similar to such harbors as Nipe, Padre, and the like, which once opened through this cañon into the Bay of Matanzas, but the bottom of which has been elevated above the present level of the bay.

We had an excellent opportunity, on going out of Matanzas on our way to Havana, to observe the plainly marked first and second terraces inside of Sabanilla Point, just beyond the pilot station. Before reaching Guanos Point the base of the second terrace is seen to be distinctly undermined, the limestone sloping very gently to the low bluff of the first terrace. After passing Guanos Point the sea has encroached upon the first and second terraces, leaving vertical bluffs which probably represent the summit of the third terrace. The fourth terrace may be seen indistinctly to the east of Guanos Point, at a height of from five hundred to six hundred feet. In the background there are indications of the fifth terrace.



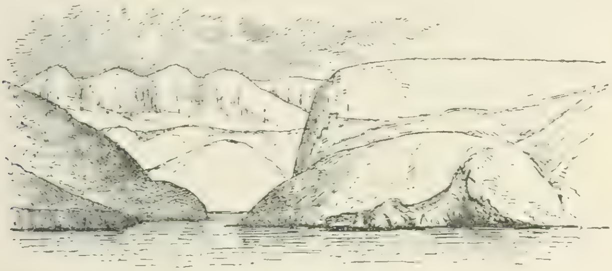
TERRACES, GUANOS POINT, MATANZAS.

## Matanzas to Havana.

### Plate I. and Plates XLIV. to XLVI.

On leaving Matanzas we come upon a stretch of coast line which is in marked contrast with the configuration of the island to the eastward. The line of shore, protected by outlying cays, which extends from Cardenas to Nuevitas, is now replaced by a nearly continuous vertical bluff, representing probably the summit of the third terrace, which extends to about opposite the Managua Paps. This low shore line belt of the third terrace is cut through by valleys following the course of the small rivers which empty on this part of the north shore between Matanzas and Havana; as, for instance, the Rio Canasi, the Santa Cruz valley, and the Jaruco River. An examination of some of the cuts made by the rivers on this part of the coast might throw important light on the history of the limestone forming the different terraces of the shore line. The height of the bluffs of the shore line, or of the hills corresponding to the third terrace, is about three hundred and fifty feet. Seen from the mouth of Canasi River Gap the limestone hills through which the river has cut its way remind one of the flat hills apparently damming the course of a river in the anthracite region of Pennsylvania.

In the background, after passing westward of the gap, the Jaruco hills come into view. They are greatly eroded as seen from the sea, and present the characteristic erosion of the vertical cliffs of the limestone hills on the eastern extremity of Cuba. The same seems also to be the case with the hills to the rear of the Santa Cruz cut. Inland behind the third terrace, where it can be traced near Santa Cruz, the general level of the land appears lower than the terrace in front of it. There seems to have been an extensive valley, parallel with the coast, formed by erosion to the rear of the shore hills. The range of hills extending to the westward towards Havana is the continuation of the Sierras de Jaruco. It seems to trend somewhat away from the coast, and also to be considerably lower. The Managua Paps are marked on the chart as not more than seven hundred and thirty-two feet high. In the vicinity of Havana the second row of hills is not of greater height than that of the third terrace. To the westward of the Jaruco River entrance there are large isolated blocks, the remnants of the soboruco after the general disintegration of the first terrace. These indicate clearly the extent of the erosion which has taken place, and which has here widened the reach of the slope of the first terrace towards the base of the cliffs or of the hills forming a part of the second terrace. Professor Dana[1] has called attention to the existence of similar huge masses of reef rock upon the shore platform of coral islands.



SANTA CRUZ GAP.

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[1] Corals and Coral Islands, p. 179.

To the westward of the Jaruco River the shore hills gradually become lower; they are not above four to five hundred feet in height, with rounded slopes, from which all traces of the terraces have been obliterated. Only here and there can we trace the first terrace. As we approach Havana from the eastward the shore hills continue to diminish in height, showing greater marks of erosion. They are not above two hundred or two hundred and fifty feet, and when the Morro comes in sight they are about a hundred to a hundred and twenty feet. It is only near the Morro that the terraces are again discernible. The first terrace is most prominent to the westward of the entrance of the harbor, while some of the hills which surround the port can readily be recognized as parts of the second and third. The higher hills to the southeast of Havana show no traces of terraces. To the westward the table-land of Mariel consists of several terraces, the steps of which are plainly visible on entering the harbor of Havana. The reef rock of the first terrace (Plate XLV.), extending westward from the Castle de la Punta to the San Lorenzo quarries, is full of fine specimens of corals, of the same species which have characterized the first terrace of the elevated reef wherever we have examined it, whether at such distant points as Saboney, Baracoa, and Cay Confites, or at Matanzas or Havana.

To the westward of Havana the coast hills are low. They are flanked by the line of the first terrace, and cut through here and there by the valleys of the small rivers taking their rise in the Mariel table-land, and in the broken range extending westward to the Sierras de los Organos. Mariel, Cabañas, and Bahia Honda are the only flask-shaped harbors found between Havana and the eastern extremity of the Colorado Reef. The Colorado Reef forms the edge of a plateau extending outside of the shore line from Bahia Honda to Cape San Antonio; there are on it comparatively few cays (Plate XIII. Fig. 5). That part of the coast resembles only in a general way the cay protected shore of Cuba extending from Cardenas to Nuevitas.

On leaving Havana for Cay Sal we kept farther out to sea than when steaming from Matanzas west. We were thus able to get a better view of the inner range of hills rising behind the low shore hill range.

## THE CORAL REEFS OF CUBA.

**Plates I. and XIII.; Plate XIV. Fig. 2; Plates XLIV. to XLVII.**

Outside of the elevated coral reef which may be said to flank nearly the whole coast of Cuba is found the growing reef, extending to ten or twelve fathoms or more wherever there is an insular platform of any width between the elevated reef and the 100 fathom line. This living reef is most irregular, occurring often merely as patches, or as spits forming small boat harbors, or as either short barrier or fringing reefs. But in many localities the general line of the reef is interrupted, either from the shifting bottom of coral sand on the sea face of the elevated reef, or from the great steepness of the shore slope, as along the south coast of Cuba from Cape Cruz to Cape Maysi, and nearly as far north as Nuevitas. Here, and along the face of the cays protecting the main shore of the island as far as Cardenas, the continental platform is much wider, and forms a coast shelf of considerable width, upon which corals flourish, principally in from three to seven fathoms of water, though they extend into depths of ten or twelve fathoms, or even more. From Cardenas to the eastern extremity of the Colorado Reef corals do not flourish, except on the Jaruco Bank, probably from the same causes which influence their distribution on the south coast. Inside the Colorado Reef as far as San Antonio exist a series of cays similar to those on the submarine bank to the eastward of Cardenas, but on a smaller scale. On the south shore, from the Isle of Pines to Cape Cruz, we have an extensive archipelago of similar structure upon a wide platform the edge of which is fringed with corals. On this plateau are, to the east of Trinidad, the Great Bank of Buena Esperanza, the Manzanillo and the Laberinto de Doce Leguas Banks, and innumerable cays dotted over its surface. The reefs between Cape Cruz, the Isle of Pines, and Cape Corrientes I have not examined, and know them only from the description of the Coast Pilot. The Colorado Reef I have only seen at two points.

On the south coast, between Cape Maysi and Cape Cruz, the prominent stretches of reefs are those to the eastward of Jucaro Anchorage, on each side of Damas Cay, and the belt extending eastward from Brava Point, where the reefs extend to the foot of the Ojo del Toro and form a sheltered reef harbor. A small patch of corals also stretches to the westward of Cape Cruz. In addition to the many cays which stud the banks between Cape Cruz and the Isle of Pines, many parts of this region are "thickly covered with mushroom-shaped coral shoals, which suddenly rise from soundings of five to eleven fathoms to just awash." These coral heads are said to be especially thick in the vicinity of Boca Grande, and extend towards the mainland. A prominent reef extends all the way from Breton Cay north of Boca Grande as far as Zarza de Fuera Cay. From that point the reef is limited to a short stretch of patches to the eastward of Trinidad. The coast there is flanked by steep rocky cliffs. The 100 fathom line is close to the shore as far as Cochinos Bay, the western shore of which is sandy, and terminates in Piedras Cay, whence a bank extends to the westward which connects with the Jardinillos Bank. The reef encircling this bank starts from Diego Perez Cay in Cazones Bay, and extends on the east face to East Guano Cay, the most easterly extremity of the bank. The southern face of the bank is "skirted by a chain of reefs," broken to form Rosario Channel. Beyond the channel a "formidable barrier coral reef" runs on the prolongation of the bank out towards Dry Shingle, to the eastern end of the Isle of Pines. Within Dry Shingle, the Calapatch Mehagon Reef is one mass of corals just awash.

The south coast of the Isle of Pines is skirted by a reef. On the western side of the island there are, as on the shores of many of the cays of the banks between Cape Cruz and Cape Corrientes, extensive patches of "soboruco," parts of the first terrace or elevated reef of Cuba. A coral reef closely skirts the whole west coast of the Isle of Pines. The Isle of Pines is by far the largest of the islands and cays which are dotted over the greater part of the wide banks off the southern coast of Cuba. The eastern extension of the Isle of Pines Bank reaches to Rosario Channel, and the western extension to Cape Frances. The coral reef skirting the west coast of the island stretches to the westward, bordering the San Felipe Cays, and from there to Cape Frances there are patches of coral reefs. From Mangle Point, near Cape Frances, to Cape Corrientes the coast is flanked by soboruco, with here and there a short stretch of coral reef.

On the north shore the Colorado Reefs extend nearly all the way from Cape San Antonio to Cabañas. There are a number of openings through the reef, with an inside channel navigable for small vessels (Plate XIII. Fig. 5). To the east of Cape San Antonio the reef is at a considerable distance from the coast line, extending across the mouth of the wide bay formed between it and Buena Vista Opening. From here the great barrier reef runs parallel with the coast, and is separated from it by an irregular belt of low cays, not many in number, compared with the endless chain of cays extending eastward from Cardenas as far as Nuevitas.

The entrances to the flask-shaped harbors of Bahia Honda, Cabañas, and Mariel are made by breaks through the extension of the barrier reef, which from the Manimar Opening to Cabañas has become almost a fringing reef. Beyond Cabañas, and as far east as Matanzas, there are but few patches of corals, one to the westward of Mariel, another off Mangles Point to the westward of Havana, and we find corals again on the Jaruco Bank and off Maya Point on the eastern side of the entrance to Matanzas. The absence of corals is undoubtedly due to the great depth immediately off shore along that whole stretch of coast line.

From Cardenas to Nuevitas extends a shore platform varying in width from five to twenty-five miles. The outer edge of this coast shelf is edged for nearly its whole distance by a narrow coral reef extending from three to seven fathoms in depth, or perhaps more. A belt of cays, many of them of great size, like Cay Coco, Cay Romano, and Cay Sabinal (Plate XIII. Figs. 1, 2), lie between the edging reef and the shore, leaving large bays or channels navigable for small boats between their western shores and the main island. Between Cardenas and Cay Coco the cays are smaller, and are either scattered in clusters over the shore platform, forming small archipelagos like those off Santa Clara Bay, Sagua la Grande, and Caybarien, or else form a belt more or less parallel with the 100 fathom line (Plate XIII. Figs. 3, 4).

These cays are the result of erosion combined with the wearing action of the sea. On their sea face we find patches of soboruco elevated to a height of from five to fifteen feet. The first terrace, formed mainly of soboruco, has been greatly eroded in the district between Cardenas and Nuevitas, and in many cases only small patches of the soboruco are left.

To the eastward of Cay Confites the edging reef little by little trends toward the shore as the shore platform becomes narrower, and to the east of Nuevitas the reef becomes a fringing reef, forming disconnected patches separated by sandy banks between Maternillos Point and Herradura Point. At some places, as off the entrance of Padre and of Nuevitas, the reefs form small reef harbors off the shore, similar to that of Alfred Sound on Inagua. They are readily distinguished, even at a considerable distance from the land, by the exquisite emerald color of the enclosed waters.

The Jaragua anchorage is an excellent example of the formation of an anchorage behind a coral reef caused by the breaking through of a channel opposite the mouth of a river. (Hydrographic Chart, No. $518^a$.)

Opposite the river Moa the coral reef which stretches across the port of Cayo Moa is interrupted, and the break forms the entrance to Cayo Moa Bay. A still better example is perhaps that of the anchorages of Yamaniguey and Cañete, where the outlying coral reef is broken through in two places, opposite each of the rivers which gives the anchorage its name. These lead into an elongated bay, the northern end of which is the Bay of Cañete and the southern the Bay of Yamaniguey.

Between Herradura Point and Cape Maysi we find only here and there patches and short stretches of fringing and edging coral reefs, or small reef harbors, as between Gibara and Sama Point, and south of Mulas Point to Banes, and between the entrances of Nipe and Port Canova. From that point the shore platform becomes wider and the reef more continuous to off Cayo Moa; it runs close to the shore from Mangle Point to Jaragua. From this place to Cape Maysi corals grow outside of the elevated soboruco reef only where the deep water does not come too close to the sea face of the elevated reef. But the living coral reefs of this part of the coast, all the way from Cape Maysi to Nuevitas on the west, and to Cape Cruz on the south coast, are of little importance.

## DISTRIBUTION OF CORALS IN THE BAHAMAS.

**Plate I. and Plates IX. to XII.**

It is interesting to follow the distribution of corals upon the banks. Excluding the edging reefs of the Great and Little Bahama Banks, as well as those of the outer edge of the smaller outlying eastern banks which have been referred to elsewhere, we find that upon the interior of the Great Bahama Bank reef corals are limited to a wide belt running east from New Providence as far as Current Island, and extending in a southerly direction. Between New Providence and the Ship Channel another extensive tract, known as the Middle Ground, is full of coral heads. It is separated from the New Providence ground by a barren area, and a similar area separates it on the south from another great patch of coral heads to the westward of Norman Cay. On examining the chart, it will be found that these areas of reef corals are in a position to be swept by the clear water of the Tongue of the Ocean and of the Northeast Providence Channel in regions where the bottom is not in constant turmoil from the action of the sea. In fact they probably grow upon the isolated patches of æolian rock, which afford the corals a solid foundation. With the exception of the edging reef on the west side of the Great Bahama Bank, on the east face of the Gulf Stream, we find the bank wholly bare of coral heads. It is one wide expanse of marl and of coral or coralline sand to the west of Andros, and to the north or northwest as well as west of the line from Andros Island to Cay Lobos. To the southeast of the termination of the Tongue of the Ocean the whole surface of the bank is dotted over with an innumerable mass of rocky heads, forming a wide field of æolian rock ledges, separated by narrow channels of from two to three fathoms of water or less, through which only small boats can navigate. This field extends almost to Nurse Channel on the south, and occupies a large triangular area reaching to the southern edge of the Jumentos Cays. Many of the heads are covered with coral growth. There are similar but more widely separated patches of rocky heads on Columbus Bank, and another extensive area flanking the southern edge of the bank from north of Blue Hole Point to Lobos Cay. In the district to the north of the line from Blue Hole Point to Diamond Point these patches are met with nearly forty miles from the edge of the bank. Another important patch of coral heads is found to the west of the southern end of the Tongue of the Ocean, south of Andros.

In addition to the Middle Ground southeast of New Providence, there is a band of rocky heads occupying the centre of the bank to the west of Norman Cay, and extending south till it reaches the sand bores to the east of Green Cay. Over the greater part of the rest of the bank the disintegration and reduction of the heads and islands and islets have been so complete as to leave the surface covered only with æolian sand and fragments in various stages of destruction, from the finest impalpable powder to fine sand, coarse sand, and flakes of coralline algæ from an eighth to a quarter of an inch in length.

On the smaller banks, the western and northern edge of Little Bahama Bank north of Bahama Island is occupied in part by heads, and the edge between Settlement Point on Great Abaco and Carrion Crow Harbor is fairly covered with heads between the few islands and islets reaching the surface. On the eastern edge of the bank the heads are interspersed between the cays, and nowhere form such a peculiar ground as the Middle Ground of the Great Bahama Bank. On Crooked Island and Caicos Banks the sunken heads are limited to a comparatively small area; in the former to the west side of the bank between Fish Cays and Castle Island, and in the latter to the area of the bank south of Ambergris Cays to South Rock and Swimmer Rock, and along the western edge of the bank. On Mouchoir and Silver Banks there is but a small area where coral heads are found.

But perhaps the most characteristic of the Bahama banks, showing the disintegration of the larger æolian islands into small isolated heads, is the Turk's Islands Bank, where the whole area to the south and west of Grand Turk Island, as far as Salt Cay on the one side and East Cay on the other, is one maze of heads with deep channels between them (Plate IX. Figs. 5, 6).

The "coral heads" described by Mr. J. A. Whipple[1] in his Journal, referred to by Professor Dana[2] as standing in fifty feet near Turk's Island, are not coral heads in the strict sense of the word. They are mushroom-shaped rocks of æolian structure, veneered with coral growth. Similar mushroom-shaped rocks of volcanic origin covered with corals occur in Kaneohe Bay, on the weather side of Oahu in the Sandwich Islands, and are common in the Bahamas and Bermudas.

These tracts of coral heads are seen to be in areas accessible to the prevailing winds, and to the food supply swept upon the banks by them and the prevailing currents. These patches, forming the Middle Ground or "coral heads" region, are without doubt clusters of æolian rock, which have not become entirely disintegrated, and which rise to very varying heights above the bottom of the bank. Upon these in many places corals and Gorgonians have obtained a foothold. Upon the smaller banks, closed on one or more sides, the corals or coral heads extend only a short distance upon the side open to the action of the prevailing winds.

Upon Little Bahama Bank we find no extensive tract of coral heads outside of those areas which may be called edging or fringing reefs, or, as on the southern face of Bahama Island, their extension a short distance upon the bank. The edging reefs may in general be said to exist along the margin of all the Bahama banks in from three to ten, or even fifteen to eighteen fathoms of water.

There seems to be nothing in the distribution of the coral reefs upon the Bahamas to show that they form anything more than comparatively thin layers of corals overlying the æolian rocks which constitute the substructure of the islands and the smaller sunken patches, and the foundation of the banks. What their thickness or extent must have been in order to form the extensive beaches which supplied the material which was blown into the dunes of the Bahama æolian land, is another question. It may not be far out of the way to assume that their thickness was no greater than that of the elevated reef of the Cuban coast on the opposite side of the Old Bahama Channel.

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[1] "The trunk which made up two thirds of its height was only fifteen feet in diameter along its upper half, and it supported above a great tabular mass one hundred feet in diameter, whose top was bare at low tide."

[2] Corals and Coral Islands, p. 133.

The difference in the formation of the coral reefs of Florida, the Bahamas, and Cuba is most striking. The coast of Cuba is characterized by the elevated reef terrace which surrounds it. In the Bahamas the corals are scattered over wide areas, either on the interior of the banks or lining their margins; they have played no part in the building up of the Bahamas. In Florida the corals have not only built up the outer keys, but also the inner line of islands, and the outer reef reaches the surface at many points. In the Bahamas the reefs are subsiding, in Florida they are stationary, and in Cuba they have been elevated.

## HYDROGRAPHY OF THE BAHAMAS.

**Plates I.–VIII., and Plate X. Figs. 4, 5.**

This brief sketch of the Hydrography of the Bahamas, of the Windward Islands, and of the Caribbean, will serve to show the relation of the coral reefs to the great banks upon which they are found. The Contour Map of the Caribbean (Plate VIII.) was prepared for my Reports on the "Three Cruises of the Blake," at the Hydrographic Office, through the kindness of Commander J. R. Bartlett, U. S. N., Hydrographer, and it is for the sake of convenient reference reproduced in this Report. For the chart of the Bahamas (Plate I.) I am indebted to Commander C. D. Sigsbee, U. S. N., the present Hydrographer of the Navy Department.

The sea face of the Bahamas indicates depths and steep slopes "fully as remarkable as any yet observed in the Pacific, even among its equatorial islands,"[1] and which are in great contrast to the more gentle slopes off the Florida Reefs.[2]

The character of the slope of the bottom off the Florida Reefs has been well described by Pourtalès[3] in the Introduction to his Monograph on

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[1] Dana, Corals and Coral Islands, p. 216.

[2] See Langenbeck, *loc. cit.*, p. 28. I am surprised to find that Dr. Langenbeck questions this. A comparison of the West Indian and Equatorial Pacific Hydrographic Charts leaves no doubt on this point.

[3] Deep-Sea Corals, by L. F. de Pourtalès, Ill. Cat. Mus. Comp. Zoöl., No. IV., 1871. See also Pourtalès, in Peterm. Geog. Mittheilungen, 1870, Heft XI.; and A. Agassiz, The Tortugas and Florida Reefs, Mem. Am. Acad., XI. 107, 1882.

Deep-Sea Corals. He has called attention to the great width (comparatively speaking), varying from three to six miles, of the slope covered by calcareous mud extending from the outer reef to the 100 fathom line. This is in marked contrast with the narrow plateau found outside of any reef on the Bahamas between it and the 100 fathom line. This plateau is nearly always a mere narrow shelf, sometimes less than a hundred feet, and rarely more than a mile in width at its greatest breadth.

An examination of the sections given on Plate IV. Figs. 1–3, and Plate V. Fig. 16, will readily show the character of the slope of the bottom off the Florida Keys, and the striking contrast of this slope with the steep, almost vertical sides of the sea faces of the edges of the coral reef banks of the Bahamas (Plate IV. Figs. 4, 5, 6, Plate V. Figs. 10, 15). Along the Florida Reef, after passing the 100 fathom line, we find a rocky belt of limestone built up of organic fragments of all kinds of Invertebrates, which extends very gradually to the 250 or 300 fathom line, and has a greatest breadth of about eighteen miles off Sombrero Light. Beyond this rocky belt, the Pourtalès Plateau, the slope becomes steeper towards the trough of the Gulf Stream. Off Cuba the rocky slope is very abrupt (Plate V. Fig. 16), and this abrupt slope is characteristic of the whole line of the Cuban coast, both north and south, except along the face of the Old Bahama Channel. Figure 16 of Plate V. is a section from Sand Key to Havana; Figure 14 is a section from Coffin's Patches to Elbow Cay on Salt Cay Bank. This shows with great clearness the gentle slope off the reef to two hundred and thirty fathoms, and the abrupt pitch of the Salt Cay Bank off Elbow Cay.

The character of the sections across the trough of the Gulf Stream becomes more clearly indicated in the sections from Fowey Rocks to Gun Cay (Plate IV. Fig. 3), from Hillsboro Inlet towards the Northwest Providence Channel (Plate IV. Fig. 2), and from Jupiter Inlet to Memory Rock (Plate IV. Fig. 1). The abrupt slope on the Bahama Bank side characterizes all the sections.

The sections of the two branches of the Old Bahama Channel passing into the Straits of Florida on the two sides of Salt Cay Bank (Plate IV. Fig. 5) show a more abrupt slope on the Cuban side than on the opposite side off Salt Cay (Plate V. Figs. 13–15), where the slope is more gentle; while the section from Anguila to the opposite bank (Plate IV. Fig. 6) shows its steepest slope off Anguila as compared with the Bahama Bank slope.

As we proceed eastward, the section from the Santa Maria Cays to the opposite shore of the Great Bahama Bank indicates that beyond the 100 fathom line the extension of the wide plateau off the main island takes a more gentle slope to the central part of the trough, while the bank slope is quite abrupt. (Plate V. Fig. 1.) It is the opposite in a section from Paredon Grande to Guinchos Cay, the Cuban slope being the more abrupt. (Plate V. Fig. 2.) In a section from Cay Lobos at right angles to the channel across to Romano Cay, the two slopes are equally abrupt. (Plate V. Fig. 3.) The same is also the case in the deeper section from Cay Romano to Diamond Point, though the Cuban slope is slightly less abrupt. (Plate V. Fig. 4.) As we go eastward the sections across the approaches to the Old Bahama Channel become deeper; in that from Maternillos Point (Cay Sabinal) to Blue Hole Point, the Cuban slope is the steeper. (Plate V. Fig. 5.) The contrary is the case in the section from Sama Point to Cay San Domingo and Ragged Island. (Plate V. Fig. 6.) The section from Cape Maysi (Point Azules) to Inagua (Plate V. Fig. 7) shows the first eight hundred fathoms to be steeper, followed by a gentler slope to the deepest part of the channel, while the Inagua slope is more uniformly steep beyond the 200 fathom line. Off Haiti in a line from Cape Isabella to Turk's Islands the Haitian slope is seen to be steeper than that of the Turk's Islands Bank. (Plate V. Fig. 8.) The sections across the Straits of Florida and across the Old Bahama Channel (Plate IV. Figs. 1–3, Plate V. Figs. 1–9) show the depths of the troughs which separate the Bahama Banks from Florida and from Cuba. The extension of some of these sections across the banks to the Atlantic give us an idea of their great expanse, and of the deep channels which cut into the banks. First, the Providence Channels, which separate the Little Bahama Bank from the Great Bank (Plate IV. Figs. 2, 3); others, like the Tongue of the Ocean or Exuma Sound (Plate IV. Figs. 4–6), which form deep bays into the bank itself; and finally the deep passages that separate the smaller banks and connect the Atlantic directly with the deep valley forming the approaches to the Old Bahama Channel.

A section run from Jupiter Inlet to Memory Rock (Plate IV. Fig. 1), across the bank to Great Sale Cay, and running off the Little Bahama Bank outside of Pensacola Cay, shows that the soundings on the bank between Great Sale Cay and Memory Rock are slightly deeper than those to the eastward towards Pensacola Cay. There seems to be little difference perceptible in the steepness of the Atlantic slope of the bank from the 10 fathom line to about three hundred fathoms, as compared with the slope off Memory Rock into the channel of the Gulf Stream. A section from Hillsboro Inlet across the Northwest Providence Channel

(Plate IV. Fig. 2) shows the southerly extension of the Little Bahama Bank separating the Gulf Stream channel and the Atlantic bight of the Northwest Providence Channel. This line runs across the bank from Mores Island to Great Abaco, and shows a much steeper sea face off Little Harbor on the Atlantic than off Mores on the Providence Channel slope. The section from No Name Cay south of Green Turtle Cay (Plate VI. Fig. 4) is interesting as showing the line of the outer ridge of cays and patches, often rising to the surface, and joining the disconnected parts of the outer reef with the belt of deeper water between it and the inner line of cays of which Green Turtle Cay is one.

The section from Fowey Rocks to Gun Cay (Plate IV. Fig. 3) across the northern part of the Great Bahama Bank to the Berry Islands shows a much steeper slope off these islands into the Northeast Providence Channel than the western slope off Gun Cay in the direction of the trough of the Gulf Stream. The line across the bank from Royal Island to the Atlantic face of Eleuthera indicates a very abrupt slope both on the channel side and on the Atlantic side, these two slopes being as steep as the slope east of the Berry Islands.

A section made somewhat farther south (Plate IV. Fig. 4), from Orange Cay across the northern extremity of Andros, the Tongue of the Ocean, Nassau, and that part of the bank lying between it and Eleuthera, shows the same features as the more northern section. The Orange Cay slope is less abrupt than the east and west slopes of the Tongue of the Ocean off Andros and off Nassau. The Atlantic slope off Eleuthera is somewhat less steep than the slope farther north. A section from Salt Cay Bank (Plate IV. Fig. 5) across to the southern part of Andros, to Green Cay, to Harvey Cay, and across Exuma Sound to Cat Island, shows a less abrupt slope on both faces of the Tongue of the Ocean, though steeper than the Santaren slope of the bank. Off Harvey Cay the slope into Exuma Sound is far less abrupt than either, and the slope from the 1,000 fathom line to the 500 fathom line off the west side of Cat Island is nearly as flat as that on the west side of the Straits of Florida. From the 500 fathom line the west face of Cat Island is as abrupt as the east face. The two slopes of Cat Island are, however, both equally abrupt, and as steep as the slopes of the outer Atlantic faces of the bank elsewhere.

A cross section somewhat farther south (Plate IV. Fig. 6), from the latitude of Anguila Island on Salt Cay Bank across the Hurricane Flats, the southern part of the Tongue of the Ocean over to Exuma Island across Exuma Sound, Conception Island, and Watling Island, shows the peak of Conception Island to be one of a ridge in continuation of Cat Island, and of which Rum Cay is another summit. The eastern slope of the Tongue of the Ocean is less steep than the western face, and the slope off Exuma is far less abrupt than that of the peaks forming Conception Island and Watling Island, both of which rise abruptly from a narrow base at a depth of over twelve hundred fathoms, and finally on the line from Cape Cabron (Haiti) to Navidad Bank the slope is equally abrupt on the two sides of the deep valley which separates these points. (Plate V. Fig. 9.) A line from Acklin to Hogsty Reef (Plate V. Fig. 10) and thence to Inagua shows very abrupt slopes in the deep channel separating Acklin from Hogsty (over one thousand fathoms) and that between Hogsty and Inagua, which is more than fourteen hundred fathoms deep. The extension of that line to the eastward of Inagua runs into over seventeen hundred fathoms, and cuts somewhat diagonally across the slope of the northern face of the deep channel to the north of Haiti.

There are unfortunately no soundings on the Atlantic face of the lines between Crooked Island Bank, Mariguana, the Caicos, Turk's Islands, Mouchoir, Silver, and Navidad Banks, to show definitely how far these banks are separate elevations, or how many may be connected together. (See Plates I. and VIII.) On the western slope the soundings seem to indicate that Turk's Islands and the banks to the eastward may be the summit of a greater bank connecting them all, and that Mariguana, Plana Cays, and Caicos and Crooked Island Banks are the summits of distinct banks separated by deep channels, much as Crooked Island Bank is separated from Long Island by the Crooked Island Passage, with nearly thirteen hundred fathoms in the deepest part. But perhaps the Plana Cays, Mariguana, the Turk's Islands, and the other banks may hold to one another much the same relation which the Mira por vos Bank summit holds to Castle Island (Plate V. Fig. 11) and the Crooked Island Bank, being separated from the last by a channel of more than nine hundred fathoms in depth and from Cay Verde by a channel with a depth of nearly fifteen hundred fathoms.

The soundings parallel to Turk's Islands Bank would seem to indicate a deep channel of perhaps a thousand fathoms between it and the Caicos Bank and the extension of the slope of Mouchoir Bank to the eastward south of Turk's Islands Bank.

We made a line of soundings to three hundred fathoms at right angles to Crooked Island Bank (Plate VI. Fig. 2) about one mile south of Southwest Point on Fortune Island. The bottom from three to five fathoms was coarse nullipore and coral sand; at from six to fifteen fathoms it became quite fine; at one hundred and eighteen it was still finer; and as no specimen was collected at either of the soundings beyond that, it must have been rocky bottom. On steaming back to our starting point for dredging, as we reached seventeen fathoms we found a few coral heads, with large patches of fine white sand between them.

On the line of soundings we ran at right angles to the bank off Exuma Harbor (Plate VI. Fig. 3) we brought up as far as seventeen fathoms the coarse sand of the banks; at eighty fathoms we found rather finer coral sand and a few broken shells; at one hundred and forty-two fathoms the bottom was composed of fine nummulitic and coral sand; the bottom was rocky at one hundred and fifty-seven and two hundred and forty-two fathoms, and at two hundred and sixty-six fathoms we struck fine coral ooze.

Neither of these slopes differs materially from the northerly slope of Hogsty Reef. Off the reef the 900 fathom line (Plate II. Fig. 1) is about four miles from the 100 fathom line. Off Fortune Island it is at about the same distance, and off Exuma Harbor the 800 fathom line is four miles from the 300 fathom line. (Plate IV. Fig. 6.) The sudden drop of these banks to the 100 fathom line occurs from the 15 to the 20 fathom line, the distance to the 100 fathom line varying from one sixth to three fifths of a mile from these soundings, or even less at other points on the banks, as off Green Cay, where it is not more than five hundred feet. Off the coast of Florida the 100 fathom line is from four to nine miles distant from the 10 fathom line, the line of the reef. (Plate IV. Figs. 1–3, Plate V. Fig. 16.)

Off the Mosquito Bank, south of Rosalind Bank, the 600 fathom line is nearly thirty miles from the 100 fathom line, and between the Rosalind and Pedro Banks the slopes east and west from each bank are fully as flat as that. (Plate IV. Fig. 7.) Off the northeastern edge of the Yucatan Bank the slope is even less, the 600 fathom line being more than thirty-five miles from the 100 fathom line. (Plate VI. Fig. 5, Plate VIII.)

The west face of the banks of the Windward Islands is often much the steeper. Off Saba the 600 fathom line is about twelve miles distant. (Plate VII. Fig. 3). The slope of the bank at the east end of Santa Cruz is about the same. (Plate VIII.) Off the west side of Barbados the 800 fathom line is over twelve miles distant. (Plate VII. Fig. 7.) At some points of the Grenadines Bank (Plate VII. Fig. 7, Plate VIII.) the 1,000 fathom line is within fifteen miles of the 100 fathom line. The eastern end of the Virgin Island Bank is steep on the sea faces; the 1,000 fathom line is in many places less than ten miles distant. (Plate VII. Fig. 1.)

An examination of the sections across Martinique (Plate VII. Fig. 5), Grenada (Plate VII. Fig. 6), the Grenadines (Plate VII. Fig. 7), Dominica (Plate VII. Fig. 8), and St. Lucia (Plate VII. Fig. 9), will show the same character of the western slope of the islands. Off the Montserrat and Antigua Bank (Plate VII. Fig. 4) this does not hold, the eastern slope being the steepest; nor is it the case with the ridge of which Barbados is the summit, the eastern face being the steeper (Plate VII. Figs. 7, 9). A section from north to south across the Virgin Island Bank (Plate VII. Fig. 2) shows a steeper slope on the southern face within the 500 fathom line.

That is, the continental slopes, or the slopes of such straits as the Florida Straits, are less steep than the ocean slopes within the area of the limestone banks.

## THE CORAL REEFS AND BANKS OF THE CARIBBEAN DISTRICT.

**Plate VIII.**

The following notes on the reefs and banks of the Windward Islands and of the Greater Antilles were made during my connection with the expeditions of the "Blake" from 1877 to 1880. As they bear upon the general theory of the coral reefs, they are now published more in detail than in the general account of the "Three Cruises of the Blake." The statements concerning the reefs of the north coast of Cuba, and of the south shore from Cape Maysi to Santiago de Cuba, are based upon personal examination, as well as those on the Florida reefs and the Yucatan Bank. In making up my notes I was obliged to consult nearly all the recently published charts of the Caribbean. This has led me to add a short account of the distribution of the coral reefs of the north coast of South America from Trinidad to Costa Rica, and also along the Mosquito, Nicaragua, and Honduras coasts, as far as Cape Catoche on the Yucatan Bank. With the exception of the coast near Aspinwall I have not examined any of the reefs or the outlying banks off the Mosquito coast, off Honduras, or those between Jamaica and the Mosquito Bank. Neither have I visited the line of shoals extending from Cayman Brac to Misteriosa Bank.

The reefs of the Windward Islands are almost without exception on their weather side, and on Saba Bank, off Anegada, and on the bank east of Santa Cruz we have horseshoe-shaped reefs following the outline of the banks at depths of from six to ten fathoms. In the majority of these cases we might look upon these curved reefs as atolls. They vary greatly in outline, following closely the depths at which they best thrive, and have usually taken from the shape of the basis upon which they have developed the outline of a more or less circular belt. The summits which have risen above the sea level are many of them more or less circular or irregularly elliptical, like St. Vincent, Grenada, and Dominica. Others are greatly indented, like the Grenadines, Martinique, Guadeloupe, and St. Martin; while among the northern islands we find, as among the smaller Grenadines, many irregularly shaped islands, as Santa Cruz, Anguilla, St. Thomas, Cat Island, and the like, along the shores of which we also find lines of irregular broken reefs.

The 100 fathom line of the banks on the west face of the Windward Islands is comparatively close to the shore, the sea face is quite abrupt, and the mass of volcanic mud and other material which is washed down during the rainy season is quite sufficient to prevent the growth of fringing reefs, which are so flourishing on the weather side. Were the banks of the Windward Islands fringed only by low, narrow islands, like the Bahama Banks, we might expect to find reefs growing on their western edge, forming thus a number of atoll-like banks, such as Crooked Island, Caicos, and Hogsty Reef.

Horseshoe-shaped or semicircular reefs exist on isolated banks in the Caribbean, as for instance on the Morant Cays, Serranilla, Serrana, and Quita Sueño Banks. There are also curved reefs simulating semi-atolls on the Mosquito and Yucatan Banks, such as Edinburgh Reef, Half-Moon Reef, and the Hobbies on the former, and the Triangles, Sisal, and Cay Arenas Reefs on the latter, besides the Alacran atoll.

Finally, off Belize we have the isolated banks of Chinchorro, Turneffe, Lighthouse Reef, and Glover Bank, all more or less irregularly elliptical, and rising from deep water beyond the 100 fathom line and inside the five hundred fathom limit, the east face of the last running rapidly into a depth of one thousand fathoms, while the slope of the Chinchorro Bank is comparatively less steep, the 1,000 fathom line being at least twenty-five miles to the eastward. Nearly the whole length of the coast off Belize, from Ambergris Point to Cape Three Points, is protected by a reef which lines the edge of the bank inside of Turneffe Island.

Let us now examine the banks of the Windward Islands formed by the 100 fathom line and compare them with the Banks of the Bahamas.

Beginning with the Grenadines Bank and throwing out of account the broad continental shelf formed by the 100 fathom line outside of Tobago and Blanca Islands, we find the bank to extend from Bequia in a southwesterly direction, forming a curved elongated plateau concave towards the west, with Bequia and Grenada as its principal islands, the latter rising to a height of over twenty-seven hundred feet, and other volcanic summits such as Carriacou, Cannouan, and a number of smaller ones scarcely rising above the level of the water. Corals flourish on the Atlantic face of the bank, forming fringing reefs or barrier reefs, or often coral ridges connecting the smaller islets. Round St. Vincent (Hydrographic Chart No. 1279, Admiralty Charts Nos. 791, 956), St. Lucia (Hydrographic Chart No. 1261, Admiralty Charts Nos. 956, 1273), Dominica (Hydrographic Chart No. 1318, Admiralty Charts Nos. 697, 956), and Martinique the 100 fathom line forms comparatively small banks. Only a narrow belt on the northern and western face of St. Vincent and St. Lucia, and a somewhat wider plateau on the eastern face of Martinique, are studded within the 20 fathom line with coral reef patches existing either as barrier reefs or as fringing reefs. No elevated reefs have been observed on Martinique, St. Lucia, or the Grenadines, while Barbados, which rises to over eleven hundred feet, is surrounded with elevated reefs forming a series of terraces round the island. These have been carefully studied by Harrison and J. Jukes-Browne. Barbados itself is the summit of an extensive elliptical bank above the 500 fathom line, the greater part extending northward nearly to the latitude of the northern extremity of St. Lucia.

The northeast coast of Barbados (Hydrographic Chart No. 1010, Admiralty Charts Nos. 956, 2485), is skirted by a coral reef from a quarter to half a mile from shore, which encircles almost the whole island. Off Palmetto Bay the reef is more than a mile off shore, but off the southeast coast a barrier reef is found, known as Cobbler Reef, extending from Kitridge Point to South Point, with a channel varying from one half to three and a half fathoms, and from a quarter to half a mile in width, with two to eight feet of water; and parallel with this is a narrow sunken reef with from seven to ten fathoms of water, separated from Cobbler Reef by a belt of water from one quarter to three quarters of a mile wide, with soundings close to the outer reef ranging from fourteen to twenty-seven fathoms. To the seaward the 100 fathom line is not more than two miles off.

Grenada (Hydrographic Chart No. 1316, Admiralty Charts Nos. 956, 2821) attains a height of from twenty-three to twenty-seven hundred feet. It is volcanic, and rises from a bank on which are the Grenadines

(Hydrographic Chart No. 357, Admiralty Chart No. 2872). The 100 fathom line is about seven miles from the east coast. The bank has twenty-seven fathoms on the east edge, diminishing to twenty about half a mile from the shore. On the western side of the island the edge of the bank is not more than two thirds of a mile from the shore.

The eastern and southern shores of Grenada are skirted by wide fringing coral reefs, following the deep indentations which characterize that part of Grenada. Between the island and the 100 fathom line a number of irregular banks rise from the main bank, with from seventeen to eighteen fathoms upon them, from near the 20 or 30 fathom line, the summits probably of islets and islands no longer reaching the surface.

The Grenadines consist of about one hundred islands and rocks extending for sixty miles between Grenada and St. Vincent, none of them attaining a height of more than eleven hundred feet. The smaller islets and islands are many of them fringed with reefs, or protected on the eastern faces by barrier reefs.

Carriacou[1] (Hydrographic Chart No. 357, Admiralty Chart No. 2872), Little Martinique, Little St. Vincent, Union, and Prune Islands are protected on their eastern faces by curved barrier reefs with deep water between the reef and the shore (one to seven fathoms), or by fringing reefs. The Tobago Cays are the centre of a complicated system of coral reefs, forming the fringing reefs of Tobago and of the smaller adjacent cays; between the islands extend broad patches of coral heads. The Tobago Cays (Hydrographic Chart No. 357, Admiralty Chart No. 2872) are in the centre of a great narrow horseshoe-shaped barrier reef, the horns of which are nearly two and a half miles apart. Outside to the eastward are the isolated reef patches known as Egg Reef and World End Reef, which rise within the 6 fathom line and are similar to the isolated reefs so common upon the bank, but most of which are covered with coralline and coral sand too deep for the vigorous growth of corals.

Cannouan (Hydrographic Chart 357, Admiralty Chart No. 2872) is flanked on the east face by a barrier reef with a belt of water from one to six fathoms inside of it. On the islands to the north the coral reefs are less vigorous. From Moustique to Carriacou there are a series of narrow, elongated ridges with from fifteen to twenty fathoms of water upon them, rising from the 20 to the 30 fathom line and following in general the 100 fathom curve.

The ridge of which the Grenadines, St. Lucia, and other Windward Islands form the summits broadens out gradually as we pass northward from Grenada. It becomes materially wider north of Martinique. This is indicated by the two small banks lying northeastward of Martinique between it and Dominica. North of Dominica, Marie Galante, and Guadeloupe with its outliers of Desirade and Petite Terre, occupy nearly the whole width of the ridge to the 500 fathom line on either side. It again increases in width at the line from Nevis to Barbuda, and attains its greatest lateral dimensions on the line from the western edge of Saba Bank to the edge of the bank east of St. Martin, one fold of the ridge extending from Saba Bank to Santa Cruz and another to Sombrero, the valley between them falling off rapidly to the Anegada Passage.

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[1] The largest of the Grenadines, rising to a height of nearly one thousand feet.

The northwest end of St. Vincent rises abruptly to three thousand feet. On the east side of Calliaqua Bay there is a lagoon protected by a reef.

The Pitons of St. Lucia are between three and four thousand feet high. At Laboise the shore is skirted by a reef.

The depths of the passages between the banks of the Windward Islands are quite moderate. Only in the channels between Dominica and Martinique and between Martinique and St. Lucia do we get a depth of more than five hundred fathoms (in one case 548 fathoms, in the other 575), the 500 fathom line joining St. Lucia and St. Vincent to the Grenadines Bank, and the 500 fathom line uniting Dominica with all the banks to the south of Sombrero with the exception of Santa Cruz and the two submarine banks between it and Sombrero.

Dominica (Hydrographic Chart No. 1318), which rises to over forty-seven hundred feet, is, like Martinique, flanked on the east by a plateau of considerable width limited by the 100 fathom line. Between it and Martinique to the eastward rises a small bank, with a depth of forty fathoms. The northeast end rises less abruptly from the sea, the soundings off the coast showing a continuation of this gradual slope, the 100 fathom line being three and a half miles off shore. It is interesting to compare the submarine slopes of Dominica, Martinique, St. Lucia, and St. Vincent with the steep slopes of the Bahama Banks, which have been considered by many writers as due to the continuous growth of coral reefs during subsidence, so as eventually to form walls of limestone rising abruptly from nearly two thousand fathoms in depth. It is surprising to find that it is the western faces of these islands which give us the abrupt slopes, while the eastern faces, on which the coral reefs are found growing upon a limestone bank of considerable width, show a comparatively gentle slope.

The 100 fathom line surrounding Guadeloupe does not include within its limits the volcanic summits of the Saintes, or the elevated limestone islands of Desirade, Petite Terre, and Marie Galante. They are separated from Guadeloupe by narrow but deep channels, having a depth of more than two hundred fathoms.

The western part of Guadeloupe (Hydrographic Chart No. 363, Admiralty Charts Nos. 885, 956) is volcanic, and rises to a height of nearly five thousand feet. Grande Terre, the eastern division of Guadeloupe, is almost a level plain. A part of the northern coast of the island is skirted by reefs with channels through it. A coral bank extends along the southern part of the northeast coast of Grande Terre and of the eastern side of Guadeloupe.

The Saintes rise to more than one thousand feet, and are skirted with patches of reefs. Marie Galante is of moderate elevation, its general appearance being flat and low. It rises gradually from south to north. The east and northeast coasts are dangerous, and skirted by coral reefs. Desirade and Petite Terre are joined by a ten-fathom bank of coral reef, the south and east sides fringed by corals.

The French surveys of Martinique (Hydrographic Chart No. 1009, Admiralty Charts Nos. 371, 956) show that the eastern face of the island from Point Laboussaye is bordered by a nearly continuous fringing reef, following the many indentations of its shores and of the small islets off the coast. Outside of this, at a distance of from one to two miles from the coast, extend a series of elongated coral banks, most of them awash, rising from the 7 to the 10 fathom line, and forming a disconnected barrier reef with wide passages between them varying in depth from four to fifteen fathoms, reaching from Caracoli Point on the north to the Vauclin Channel on the south. Martinique rises to a height of nearly four thousand feet.

St. Eustatius (Hydrographic Chart No. 1011, Admiralty Charts Nos. 487, 2600) is volcanic, and rises to a height of over nineteen hundred feet. The greater part of the eastern coast is fringed with corals; on the southeast coast coral patches are found. Saba, also volcanic, rises perpendicularly more than twenty-eight hundred feet from the sea. The 100 fathom line is not more than half a mile from the west side, and only three cables from the west face. It is so abrupt that no corals grow upon its sides.

The eastern edge of Saba Bank (Admiralty Charts Nos. 130, 487, Hydrographic Chart No. 1002) is fringed with a narrow ledge of corals nearly thirty miles in length, with six to ten fathoms of water. The bank is about thirty by twenty miles. To the westward of the coral reef, with the exception of a few coral patches, there are nine to ten fathoms of water; the bottom is clean white calcareous sand, with a depth of from twelve to fifteen or twenty fathoms, gradually increasing to thirty fathoms, where the slope becomes very abrupt.

St. Bartholomew is nearly one thousand feet high, and rises from a flat bank of considerable extent, composed chiefly of broken shells, white sand, and corallines.

St. Martin, and also the smaller islets near St. Bartholomew (Hydrographic Charts No. 1002, Admiralty Chart Nos. 130, 2038), are fringed with reefs on the eastern and greater part of the northern faces. On the shores of St. Bartholomew itself there are but few coral patches. St. Martin is nearly thirteen hundred feet high. Tintammare is bordered on all sides except the west by coral reefs extending one quarter of a mile from shore.

A small inverted-comma-shaped bank is formed by the 100 fathom line uniting Montserrat (Hydrographic Chart No. 1011, Admiralty Chart No. 254) and Redonda, both of which are volcanic rocks. The isolated peaks of Montserrat rise to three thousand feet above the sea. It is fringed here and there with corals on the east end. Redonda reaches a height of six hundred feet.

The volcanic island of Saba (Admiralty Charts Nos. 130, 487, Hydrographic Chart No. 1002) stands by itself, and to the westward of it rises within the 100 fathom line the Saba Bank, on the southern and eastern face of which a belt of coral reef is found.

An elongated bank is formed by the 100 fathom line uniting Nevis, St. Kitts, and Eustatius.

Nevis (Admiralty Chart No. 487, Hydrographic Chart No. 1011) is also volcanic, and over thirty-five hundred feet above the sea. With St. Kitts and St. Eustatius (Hydrographic Chart No. 1011, Admiralty Charts Nos. 487, 2600), it stands upon a bank entirely detached from the adjoining islands, separated by channels of more than two hundred fathoms in depth. From the south end of the bank a remarkable coral ledge about a mile in breadth extends along its southwest edge for a distance of five miles, and has from eight to ten fathoms on it, with deeper water within. Except on the west side, the shore is fringed with a coral reef extending three quarters of a mile out to a depth of ten fathoms.

St. Kitts (Admiralty Chart No. 487) rises to a still greater height, viz. over forty-three hundred feet; a great part of the eastern face of the island is flanked by a fringing reef.

Antigua (Hydrographic Chart No. 1004, Admiralty Charts Nos. 917, 2600), which rises to a height of thirteen hundred feet, is near the southern extremity of a bank formed by the 100 fathom line, at the northeastern end of which is placed Barbuda, an island composed of limestone, rising to a height of two hundred feet. The shores of Antigua are deeply indented, especially the northern and eastern faces of the island. It lies upon the middle of the eastern edge of the same bank as Barbuda, the general depth of which is from seven to eleven fathoms, with a coralline and coral sand bottom. It is surrounded by many small islands and islets, and edged on the east, south, and north sides with fringing and barrier reefs, leaving only intricate passages leading into the deep sounds of the island. From the entrance to North Sound the patches of reefs and banks extend in an arc to the westward as far as Diamond Bank, the most westerly of these coral reefs. The Highlands are apparently composed of three terraces, the highest of which is two hundred feet.

From the southeast end of the eastern shore of Barbuda (Hydrographic Chart No. 367, Admiralty Charts Nos. 1997, 2600) a coral ledge skirts the shore at a distance of half a mile; a reef also extends one and a half miles off the north shore, the depth being thirty fathoms within a mile of it; and reefs run off the south coast nearly seven miles in a southwest direction. Barbuda is connected with Antigua by a bank with seven to thirty fathoms of water.

Between Antigua and Guadeloupe an isolated bank rises to a depth of forty-three fathoms, and a similar bank is found to the southeast of the bank limited by the 100 fathom line, of which the principal summits are St. Bartholomew (992 feet), St. Martin (1360 feet), and Anguilla (213 feet). With the exception of Anguilla, they are volcanic summits. They are surrounded by a number of smaller islets of the same structure.

Sombrero is steep and rises to forty feet from a small bank about four miles long. It is composed of recent limestone (Julien), very much honeycombed, and rises abruptly within the 500 fathom line. In a line between it and Santa Cruz rise two submarine banks, the one with a minimum depth of three hundred and seventy-six fathoms, the other with a depth of three hundred and eighty-three fathoms.

Anguilla (Admiralty Charts Nos. 130, 2038, Hydrographic Chart No. 1002) is not more than two hundred and thirteen feet high. The south shore and the eastern end of the north shore are fringed with coral reefs. An extensive reef runs westward from Scrub Island within the 10 fathom line for over twenty miles, with passages to the west of the Pear Cays and eastward of Dog Island.

## Santa Cruz, the Virgin Islands, and the Greater Antilles.[1]

Santa Cruz is the broad summit of the bank which extends east of the island for a distance of nearly twelve miles, and forms a narrow belt round it. With the exception of a small part of the western end of the north shore and of the western side, Santa Cruz is fringed along its whole coast with corals, forming either fringing or barrier reefs off the north side, and a broad belt of fringing and barrier reefs skirting the south side, of the island. Round the eastern extremity of the bank to the east of the island an extensive reef (Lang Bank) follows the outline of the 100 fathom curve. On this we find six to nine fathoms. It extends on the south face of the bank from the east end to opposite the eastern point of Santa Cruz (Admiralty Charts Nos. 130, 485, and Hydrographic Chart No. 1002).

The Virgin Island Bank, which includes within the 100 fathom line the Virgin Islands and Porto Rico, is separated from the banks to the southeast of it by a deep cañon of over one thousand fathoms, connecting the Atlantic with the Santa Cruz deep of more than two thousand fathoms, separating that island from the Virgin Islands. Porto Rico is the easternmost of the greater West India Islands, and occupies nearly the whole width of the western end of the Virgin Island Bank.

The Virgin Island Bank (Admiralty Charts Nos. 106, a, b, c, 130, and Hydrographic Charts Nos. 1002, 2008) presents very much the same characteristics as the Grenadines Bank. It is the summit of an elongated bank seventy-five miles in length, reaching from Porto Rico to Anegada, and from twenty-three to thirty miles wide. Some of the larger islands which crop out upon the southern edge of the bank, like Crab Island, Tortola, Culebra, St. Thomas, and Virgin Gorda, attain a height of more than fifteen hundred feet, while there are a great number of smaller islands, islets, and rocks barely reaching the surface, all of which are of volcanic origin, Anegada alone being composed of recent reef limestones.

The sea face of Anegada (Admiralty Chart No. 130, Hydrographic Charts Nos. 1002, 2008) is fringed with a coral reef extending to a depth of about thirteen fathoms. Off the east point the reef spreads out upon a broad bank over three miles in width, which also extends along the western face of the island and is studded with coral heads. A wide band of coral heads extends from East Point, known as the Horseshoe Reef, following in a general way the line of the 100 fathom curve. The reef is broken to form the Necker Island Passage, and opposite Virgin Gorda a long narrow belt of corals extends nearly the length of the bank as far as Crab Island, with from twelve to seventeen fathoms of water, forming a regular wall with a belt of deeper water on the inside of from twenty to thirty fathoms, and from two to five miles wide.

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[1] The reefs of Cuba have already been described in a separate chapter.

Nearly all the islands of the Virgin Bank are skirted on their eastern and southern faces with patches and stretches of coral heads, often forming extensive fringing reefs. This is the case with Virgin Gorda, Tortola, St. John, St. Thomas, Culebra, and the eastern end of Crab Island.

The Virgin Islands lie on the southern edge of a vast bank of soundings extending from Porto Rico, which rises to a height of thirty-seven hundred feet, to the east of Anegada, which has an elevation of not more than thirty feet. The contrast between the soundings off the north and the south face of the bank is quite marked. The southern edge of the bank is not more than seven miles from the cays, while the northern edge extends nearly thirty miles to the north of the islands. The general depth of the bank varies from seven to thirty fathoms. Tortola rises to a height of nearly thirteen hundred feet, and Virgin Gorda to a little less. St. Thomas (Admiralty Charts Nos. 130, 2183, Hydrographic Chart No. 1002) rises to a height of over fifteen hundred feet, and is surrounded by many small islands and cays fringed with corals.

The 500 fathom line forms an elongated bank round Aves or Bird Island, which is the summit of a wide fold at less than one thousand fathoms running nearly north and south from Saba Bank to Bird Island in the direction of Venezuela to about the latitude of Bequia, a bay with a minimum depth of two thousand fathoms running between it and the Windward Islands to the latitude of the southern extremity of Dominica.

Aves Island (Hydrographic Chart No. 40, Admiralty Chart No. 2600) is only ten feet above the level of the sea; it is composed of coral rock skirted all round by a reef except on the west side. The islet rises from a bank of considerable extent, which has not been defined by soundings.

The south shore of Porto Rico (Admiralty Charts Nos. 130, 2600, Hydrographic Chart No. 40) is fringed with reefs about four miles off shore. Mona Island is formed of white perpendicular cliffs about one hundred and seventy-five feet high, full of holes, with numbers of grottos and caves.

A part of the east coast of San Domingo (see General Charts of the West Indies, Hydrographic Charts Nos. 40, 373, Admiralty Chart No.

393) is formed of remarkable limestone cliffs from one hundred and fifty to two hundred feet high. The projecting parts of the island in the vicinity of Aquin Bay consist of very remarkable bold white cliffs and hills resembling chalk, which occur both on the south and on the north coasts. There are coral reefs all along the shores of the island. The 100 fathom line adds but little to the extent of San Domingo, which is separated from Porto Rico by a channel, the greatest depth of which is only two hundred and sixty fathoms. The area of Jamaica would be greatly extended on its southern face by the addition of the plateau formed by the 100 fathom line. Extensive areas of elevated tertiary limestones have been traced along the coasts of Jamaica and of San Domingo.

Between the eastern point of Haiti and Jamaica are the small island of Navassa and the Formigas Bank. Navassa (Hydrographic Chart No. 379, Admiralty Charts Nos. 461, 486) is about three hundred feet high. It rises from a small bank of soundings one third to three quarters of a mile broad. There is a patch of corals on the north end of the island. Formigas Bank (Hydrographic Chart No. 373, Admiralty Chart No. 486) is eight miles in length; the bottom is rocky, with a general depth of from five to seven fathoms. There are narrow veins of sand near the edge, in from nine to eighteen fathoms.

To the southeast of Jamaica are the Morant Cays, a group of small cays seven to ten feet high, forming with the adjacent reefs a crescent bank convex to the southeast of about three by one and a half miles wide. These cays rise from an elongated bank about twelve miles by four within the 100 fathom line, with depths close to it ranging outside of the reef from seven to eighteen fathoms, and thirty to fifty near the edge of the bank. A terrace is said to rise seventy-five feet all round the island, composed of ringing and honeycombed limestone. The Albatross Bank lies to the northeast of the Morant Cays, and is a similar bank; it carries, however, from nineteen to thirty fathoms close to the 100 fathom line, and is marked on the charts as coral sand.

Fringing and detached reefs abound on the south shores of Jamaica. They are especially numerous from Morant Point to the west of Kingston Harbor as far as Portland Point, although they extend, irregularly distributed in favorable localities, to the western extremity of the island off Alligator Point, and from Pedro Bay to St. John's Point (Admiralty Chart No. 255, Hydrographic Charts Nos. 347, 373).

### The Banks of the Caribbean Sea.

Between Jamaica and Honduras and off the Mosquito Bank rise a number of banks, the most easterly of which is the Pedro Bank (Hydrographic Chart No. 373, Admiralty Charts Nos. 450, 486), which rises abruptly from depths of three hundred and fifty to five hundred fathoms. It is irregular in shape, nearly a hundred miles long east and west, quite narrow at the eastern end, not more than nine miles, while at the western end it is fifty-five miles broad. The surface of the bank is level, ranging from nine to fifteen fathoms except near the eastern and the southeastern edge of the bank, where there are many shoals and cays said to consist of white limestone. The bottom on the bank is generally white sand and fragments of corals, but there are patches of coral heads and of coralline algæ. Portland Rock is thirty-two feet high; Plover Rock is two to three feet high. Off the Pedro Cays, about twelve feet high, reefs extend parallel with the 100 fathom line between the cays. Banner Reef is just awash.

Next comes to the westward the Rosalind Bank (Hydrographic Charts Nos. 373, 394). It is pear-shaped, nearly sixty-three miles long, and ranging in width from fifteen to thirty-five miles. The only shallow ground upon it is near the southeast end, where there is a wide coral belt nearly three miles wide, and trending in a northeasterly direction for fourteen miles, with depths upon it varying from four to ten fathoms. On the eastern face there is also a second ledge about thirteen miles north of the first, eight by four miles, on which we find eight fathoms. The general depths on the bank vary little from ten to twenty fathoms; the bottom is coarse coral, coralline sand, and broken shells.

Between Rosalind and Mosquito Bank lies a narrow bank, thirty-seven miles long, not more than ten miles wide, with from thirteen to thirty-five fathoms close to the 100 fathom line. This bank is separated from the Mosquito Bank by a narrow channel with a depth of about one hundred and seventy-five fathoms, and by a somewhat deeper channel from the Rosalind Bank.

To the south of Pedro Bank rises the small, isolated Bajo Nuevo Bank (Hydrographic Chart No. 379, Admiralty Chart No. 391) on which there are two remarkable hook and bow shaped coral reefs rising from the 5 fathom line on the eastern and southern face of the bank. On the bank the soundings vary from six to fifteen fathoms close to the 100 fathom line.

To the south of Rosalind are the smaller banks, the most northerly of which is the Serranilla Bank. It is somewhat circular in outline, and about twenty-four miles in greatest length. There is a general depth of from five to fifteen fathoms upon it; the bottom on the bank is coarse coralline and coral sand. The bank is steep, the slope increasing rapidly in depth from twenty to one hundred fathoms and more. On the east face of the bank there are three small cays, from which extensive reefs run along the eastern face more or less parallel with the 100 fathom curve from Northeast Breaker to Beacon Cay. Farther south, east of the Mosquito coast, are the Serrana and Roncador Banks to the eastward; half-way between them and the Mosquito Bank comes the line of the Quita Sueño Bank, of Old Providence, of St. Andrews, and of the Courtown and Albuquerque Cays (Admiralty Charts Nos. 379, 1498, Hydrographic Charts Nos. 373, 394).

Both Old Providence (Hydrographic Charts Nos. 395, 1372, Admiralty Chart No. 1334) and St. Andrews (Hydrographic Charts Nos. 391, 945, Admiralty Chart No. 1511) resemble in their general features, but on a smaller scale, some of the volcanic Windward Islands, upon the weather side of which coral reefs flourish. The greatest height of the volcanic peaks of Old Providence is nearly twelve hundred feet; from the central peaks spurs run off terminating in shore peaks of from three to seven hundred feet in height. Besides the main island, there are upon its bank the small island of Santa Catalina and a couple of smaller cays; the bank carries from two to ten fathoms of water. A barrier and fringing reef extends round the island, and a long reef stretches out north. St. Andrews is only three hundred feet high. A few small cays are scattered upon its bank; its northeastern end is flanked by a reef. Upon Courtown Bank (Hydrogaphic Charts Nos. 391, 945, Admiralty Chart No. 1511) a barrier reef extends across it from the northern end to within half a mile of the southern extremity. The northern and eastern sides of Albuquerque Cays Bank are skirted by a reef.

The eastern face of Quita Sueño Bank (Hydrographic Chart Nos. 394, 945) is flanked by a reef for twenty-five miles, leaving only a small part of the bank clear at each end. The north and east edges of Roncador Bank (Hydrographic Charts Nos. 373, 395, 945, 1374, Admiralty Chart No. 1478) are fringed by a coral reef. The cays upon it are composed of broken coral blocks and coral sand.

The extreme east end of Serrana Bank presents a solid crescent-shaped reef. The space within the horns is crowded with detached shoals, with from five to ten fathoms alongside. The east face of the bank is abrupt, no bottom at one hundred fathoms one quarter of a mile from the 10 fathom line; the south edge of the bank is edged by a reef.

Misteriosa Bank (Hydrographic Chart No. 966) is the western extremity of a submarine chain flanking the northern side of Bartlett Deep to the east of Cape Cruz, of which Cayman Brac and Little and Grand Cayman are the summits, and to the north of which the isolated Pickle Bank rises, upon which are from ten to forty fathoms of water, with a coral sand bottom. Misteriosa Bank is twenty-four miles long, oval in shape, with general depths of from ten to twelve fathoms and a coral bottom. To the south of it are four other small banks with from thirteen to nineteen fathoms of water. Still farther south are the Swan Islands, but the limits of the bank from which they rise have not been determined. The islands are separated by a coral reef; they are flat, sixty feet in height, and bounded by a bold, rocky shore. The soundings upon the bank are from six to thirteen fathoms, increasing rapidly to forty fathoms on the western side of the islands.

Grand Cayman (Hydrographic Charts Nos. 43, 373, 947, Admiralty Chart No. 462) is about forty feet high. At the southwest end a reef runs out half a mile. All but the west side is skirted by a fringing or barrier reef, which is steep to for a distance of a quarter of a mile to a mile. At the east end it forms a solid barrier for the distance of a mile; on the south side there are several small cuts through the reef. At the western end there is a large circular lagoon, Great Sound, with from one to two fathoms, and a passage leading through the reef with from two to two and a half fathoms. Cayman Bank, about ten miles west of Grand Cayman, is a ridge of coral five miles long and half a mile broad, with a depth of from fifteen to twenty fathoms. The edge drops very suddenly to more than one hundred fathoms.

The highest point of Little Cayman (Hydrographic Charts Nos. 43, 373, 947, Admiralty Chart No. 462) is forty-eight feet. The south coast is skirted by a fringing and barrier reef with a wide passage on that side. The north coast is only fringed in part. The 100 fathom line of the bank is generally half a mile from the shore.

Cayman Brac (Hydrographic Charts Nos. 43, 947, Admiralty Chart No. 462) rises to fully one hundred and thirty feet. The north and south coasts are skirted by a broken reef; the 100 fathom line is about half a mile off.

## The Coral Reefs along the North Shore of South America.

Along the north shore of South America (Hydrographic Charts Nos. 40, 964, Admiralty Charts, West India Sheets VIII. to XI., Nos. 394, 395, 396) and the adjacent islands there are many points where coral reefs take a great development. With the exception of the central part of the north coast of Tobago, which rises from a bank of about forty fathoms, the island is fringed with disconnected fringing and barrier reefs, growing most luxuriantly off the northeast end of the island and near the southwest extremity (see Hydrographic Chart No. 354, Admiralty Chart No. 505). The Testigos are surrounded by coral reefs on the eastern face of the bank from which they rise; they are within the broad belt of the 100 fathom line, and carry from twenty-three to thirty-eight fathoms near them. Detached patches of coral reefs extend along the coast from the Gulf of Paria to the Gulf of Cariaco. Margarita Island is flanked by fringing and barrier reefs on the eastern and western coasts, as well as along its whole southern shore. The islands of Cubagua and Coche, which lie between it and the mainland, are likewise skirted on the eastern faces with reefs. Orchila is low and flat, surrounded by reefs on the eastern face. Los Roques are a group of cays rising from a bank of twenty-three miles in length; the greater part of it is covered by coral heads, and its sea face is edged by coral reefs. The Islas de Aves are banks similar to Los Roques. Buen Ayre Island is fringed by a reef on the eastern and northwestern extremities of the island. Little Curaçoa is a coral islet with steep sides. The south side of Curaçoa is bordered by a bank of coral reefs.

From Cape Codera to Cape St. Roman the coast is fringed with long stretches of coral reefs, from Codera to Caracas, and on both sides of Punta Tucacas, east of Zamuro Point. The whole eastern face of the peninsula of Paraguana is fringed by corals. West of the Gulf of Venezuela, with the exception of the fringing reefs along the eastern and northern coasts of the Guajira peninsula, the reefs along the north shore of South America as far as the Mulatas archipelago are limited in extent, occurring on comparatively short stretches of shore interrupted by long reaches of sand beaches (Hydrographic Chart No. 964). The Mulatas archipelago, a number of islets and islands from two to ten miles off shore, extends from Pajaros Island to off Point San Blas, a distance of eighty miles: they are fringed by reefs rising from seven to ten fathoms of water (Hydrographic Chart No. 945). The north shore of the coast of Panama and of Costa Rica is, with that exception, free of exterior reefs. The north side of the interior of Chiriqui Lagoon is thickly studded with detached shoals of corals and coral patches.

## The Coral Reefs and Banks of the West Coast of the Caribbean Sea.[1]

It is to be noted that on the western Florida Bank, as well as on the Yucatan Bank, where the conditions of depth would seem to be most favorable for the growth of corals, in the one case the coral reefs are limited to a few isolated patches like Arenas Cays (Hydrographic Charts Nos. 403, 1233, Admiralty Chart No. 1209), Sisal Reef (Hydrographic Charts Nos. 403, 1235, Admiralty Chart No. 1206), Madagascar Reef (Hydrographic Chart No. 1235), the Triangles (Hydrographic Charts Nos. 403, 1239), Obispo Shoals (Hydrographic Charts Nos. 403, 1239, Admiralty Chart No. 1830), the Arcas Cays (Hydrographic Charts Nos. 403, 1234, Admiralty Chart No. 1829), and the Alacran atoll (Hydrographic Charts Nos. 403, 966, 1234, 1235, 1240, Admiralty Chart No. 1203); while in the other case they form a narrow thread parallel with the course of the Gulf Stream outside of the Florida Keys from north of Key Biscayne to the Tortugas.[2]

Along the west coast of the Gulf of Mexico (see Coast Survey Chart of Gulf of Mexico, $\frac{1}{1,200,000}$) the corals are wanting, with the exception of a few isolated patches of coral reefs off Vera Cruz coming up from sixteen fathoms of water (Hydrographic Chart No. 967, Admiralty Chart No. 523), which, although noted in the Admiralty West Indian Pilot, had failed to come to the notice of scientific men, have been described by Professor Heilprin.[1] Is their absence due to the limited amount of food brought by the current across the Yucatan Bank, sweeping as it does northward towards the Tortugas and washing the shores of the Florida Keys? The exposure of the coast of British Honduras and of the Yucatan and Mosquito Banks to the influence of the prevailing winds and currents, bringing with them a vast supply of pelagic food, is probably the principal cause for the abundant growth of coral reefs in all favorable localities on the Yucatan and Mosquito Banks and along the British Honduras coast, as well as upon the weather faces of the Serrana and Quita Sueño Banks, the Roncador Reef, Old Providence, St. Andrews, and the Courtown and the Albuquerque Cays.

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[1] The reefs of Cuba have been described in a separate chapter.

[2] Since my explorations of the Bahamas and Bermudas I am convinced that a more detailed examination is needed to ascertain how far south the older miocene rocks of Florida extend, and to what depth they are covered by the recent coral growths from Key Biscayne to the Tortugas. An exploration of the inner line of keys may show perhaps how far the configuration of the western part of the Florida Bank to the south of Cape Sable may be due to a slight subsidence, and how far this has been concealed by the growth of corals to form the outer reef, and by the deposition upon these older rocks of coral material which has formed the inner line of cays, or how far erosion has been the main factor in shaping the topography of the submerged southern part of Florida and of the adjacent keys. Borings alone can determine this question, owing to the quantity of coral silt which has been deposited upon the mud flats north of the keys, unless we may succeed in finding somewhere among the inner keys an outcrop of the older miocene or perhaps later tertiary rocks.

For an account of the Florida Reefs see L. Agassiz, Ann. Rep. U. S. Coast Survey, 1851, Mem. Mus. Comp. Zoöl., Vol. VII. No. 1, 1880; A. Agassiz, The Tortugas and Florida Reefs, Mem. Am. Acad., Vol. XI., 1882; Three Cruises of the "Blake," Bull. Mus. Comp. Zoöl., Vol. XIV., 1888; and Coast Survey Charts, Nos. 166, 167, 168, 169.

## The Reefs of the Yucatan Bank.

On the Yucatan Bank (Hydrographic Charts Nos. 1234, 1235), with the exception of the Alacran atoll, the reefs are merely more or less irregularly shaped patches, either surrounding the cays wholly, or reaching out from them, and rising generally from the 3 to 5 fathom line of the bank itself. This is the case with the Arcas Cays and the Triangles (Hydrographic Chart No. 1239). The Obispo Shoals (Hydrographic Charts Nos. 403, 1239, Admiralty Chart No. 1830) and the Sisal Reefs are small irregular patches rising from the 5 or 6 fathom line, while Madagascar Reef is a narrow coral ridge about two miles long, rising from the 7 to 11 fathom line with from one and a half to three fathoms of water upon it. On the extension of the Yucatan Bank plateau to the westward there are also a few patches of reefs off the Barra de Tuxpan and scattered patches off Champoton, but neither these nor the reefs off Vera Cruz, along the inshore edge of the narrow shore platform of the west coast of the Gulf of Mexico, can be considered as reefs of any importance. And indeed they are so unimportant that it was not unnatural for Darwin and Dana to speak of the Mexican coast of the Gulf of Mexico as free from coral reefs.

Along the Yucatan coast to the south of Cape Catoche, Mugeres Harbor (Hydrographic Charts Nos. 402, 1379) is formed by the extension northward of the two fringing reefs which run along the east and west face of the island and pass into the shifting ledges forming the Blancas Lagoon. Corals are reported upon Arrowsmith Bank in twelve fathoms.

Cozumel (Hydrographic Charts Nos. 402, 1380) is flat, not more than forty to fifty feet in height. It is sandy, with rocky ledges separating the beaches. It is separated from the mainland by deep straits. From the northern end of the island a sand bank extends eleven miles. The west side has deep water close to the shore.

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[1] Proc. Phil. Acad. Nat. Sci., 1890, p. 303.

Espiritu Santo and Ascension Bays (Hydrographic Charts Nos. 402, 1380, Admiralty Chart No. 1795) are both protected by narrow reefs extending across the mouth of the harbors. These reefs rise from a depth of from four to six fathoms.

## The Reefs and Banks of British Honduras.

The extensive barrier reef running along the edge of the Honduras Bank reaches from Ambergris Cay to the southern part of the Gulf of Honduras, and forms a broad stretch of reef building patches separated from the coast by a wide channel parallel with it and carrying from ten to twenty fathoms. It resembles, on a much smaller scale, the great Australian barrier reef. The Honduras Reef rises in from six to seven fathoms, and the depth gradually increases as we go westward towards the deeper parts of the channel which form the inland sea separated from the Caribbean by the wide barrier reef composed of numerous detached patches and cays. The reef varies in width from one or one and a half miles at the southern end to sixteen and even twenty miles in the latitude of Gladden Spit, where the channel is divided by an irregular area of banks, cays, and patches of coral heads, with many narrow but deep veins of water between them. These banks are often awash, or rise from six to seven fathoms, and carry from one and a half to three fathoms. One of the channels leading across the bank, the English Cay Channel, carries more than twenty fathoms. The principal passages through the reef carry from four to six fathoms, and rapidly open into the deeper water leading to the main inside channel. Chetumal Bay and the adjoining territory to the north and east seem to indicate the manner in which the cays and barrier reef of Honduras have been formed. The outer sea face, as well as the inner eastern line of the bay, is edged by a reef. If a general subsidence or erosion of the Honduras coast is going on, that part of it must soon be changed into a bank like the banks flanking the present coast, or into something similar to the barrier reef near Point Gladden, the small banks and cays indicating the position of the former low ranges of hills and valleys such as we find on the lowlands to the east of Chetumal Bay. Subsidence or erosion, or both, have formed the outline of the bank; coral reefs have edged it, but there is nothing to prove that they have formed the land intervening between the existing lines of reefs. The bank limited by the 100 fathom line off British Honduras is narrow compared to the wide bank off the Mosquito coast, the width of which at its northern extremity seems to a certain extent to influence the growth of coral reefs and patches, for they are by no means so flourishing as upon the narrow bank off the Honduras coast.

In addition to the barrier reef off British Honduras there are a number of outlying banks which from their description resemble the smaller of the Bahama Banks. They are the Chinchorro Bank, the Turneffe Islands, and Lighthouse and Glover Reefs, which in a certain degree resemble irregular atolls. They all lie within the 500 fathom line. The greater part of Chinchorro Bank (Hydrographic Charts Nos. 394, 1072, Admiralty Chart No. 1796) is bounded by a reef. There are several openings into the interior which are navigable for small fishing vessels. Lighthouse Reef (Hydrographic Charts Nos. 394, 1120) is bounded by an edging reef; the north end forms a half-moon curve about four miles in diameter; the east side of the reef is steep to. The Turneffe Islands (Hydrographic Charts Nos. 394, 399, 1120), are an extensive cluster of mangrove islands on a bank of coral and sand thirty miles long and from four to nine wide. The cays are all skirted, at a short distance from both the east and west sides, by a barrier reef with an inside channel having over two fathoms. Glover Reef (Hydrographic Charts Nos. 394, 1120), with the exception of a small part of the east side, is fringed by a barrier reef.

## The Mosquito Bank.

Upon the Mosquito Bank (Hydrographic Charts Nos. 394, 945), as upon the Yucatan and Honduras Banks, there are patches and reefs rising upon the surface, not entirely covering it, but scattered, as we find the Arcas, Triangles, Madagascar, Alacran, and other small reefs. They are more numerous upon the Honduras Bank, and get the full benefit of the prevailing winds, and of the sweep of the currents against their sides and over their surface.

There are a great number of irregular patches of coral reefs from Monkey Point north of the Bluefield Lagoon (Hydrographic Charts Nos. 391, 1292, Admiralty Chart No. 1504), within four or five miles from the coast. From Pearl Cay Lagoon to Man-of-War Cay there are a number of small irregularly shaped banks rising from a depth of eight to ten fathoms, the largest of which are the reef patches of the Pearl

Cays and of Tyra Bank. The distance of these reefs from the shore varies from one to fifteen miles.

The small banks from which the Pearl Cays (Hydrographic Chart No. 392, Admiralty Chart No. 1503) rise, which themselves rise from the Mosquito Bank at depths varying from eight to twelve fathoms, are fringed and covered by irregularly shaped reef patches, generally placed on the eastern and northern sides of the banks adjoining the cays or connecting them. Long Reef Bank has a continuous reef on its eastern edge rising from a depth of three to four fathoms.

Great Corn Island (Hydrographic Chart No. 392, Admiralty Chart No. 1476), twenty-nine miles east of the Bluefield River, rises to a height of three hundred and seventy feet. It is probably of volcanic origin. The northern and northeastern shores of the island are protected by an elliptical coral reef forming a great curve at a distance of about a mile from the shore, with numerous heads and patches between the outer reef and the shore. Off the island the bank has a depth of from thirteen to twenty fathoms, the reef rising from a depth of four to six fathoms. Off Little Corn Island there is a similar reef, about a quarter to half a mile from the shore, with two to three fathoms upon it, which skirts the eastern and northern face of the island. Great Corn and Little Corn Islands are seventeen or eighteen miles from the 100 fathom line, the bank sloping seaward very gradually from twenty or thirty fathoms.

Upon the eastern half of the Mosquito Bank, between the Corn Islands and the cluster of reefs and banks to the south of Edinburgh Reef, there are a few isolated patches of coral in from six to ten fathoms. The Mosquito Shoals and the Morrison Cay Bank are the centre of an extensive area of rocky heads and of coral patches south of Edinburgh Channel. Both banks are skirted by an irregular undulating line of reefs. Edinburgh Reef is crescent-shaped, convex to the east, rising from thirteen fathoms, with fourteen fathoms to the westward of the reef (Hydrographic Chart No. 945). North of Edinburgh Reef there is also a cluster of small isolated coral patches and banks, of which the most prominent are the Main Cape Bank, the Half-Moon Reef and Cays, and the Alargate Bank.

The Mosquito Bank extends as a narrow belt varying from four to forty miles along the north shore of Honduras from Patook Point to the Gulf of Honduras. That part of the bank is free of shoals, with the exception of a few patches to the east of Cape Honduras. On the outer edge of the bank, to the eastward of Truxillo, twenty miles from the coast, is Utilla Island. Utilla with the cays and islets at its western end may be considered as the remnant of the former extension of the north coast of Honduras: it is remarkably clear of coral patches. With the exception of a narrow ridge rising to a height of two hundred and ninety feet at the eastward, the greater part of the island is low and swampy. To the northeast of Utilla are the islands of Roatan and Bonacca, both within the 500 fathom line. Bonacca (Hydrographic Chart No. 396, Admiralty Chart No. 1718) reaches to a height of over twelve hundred feet: it rises from the 5 fathom line upon the eastern end of an elongated bank formed by the 100 fathom line. It is surrounded by clusters of coral bars and cays, which are most abundant on the southeast face of the island. Roatan (Hydrographic Chart No. 394) has an average height of three to five hundred feet: its highest point is nearly eight hundred feet. Its northern shore and that of the eastern islets are all skirted by coral reefs, which sweep round the eastern face of the Roatan Bank and extend in irregular stretches along the southeast coast, where the shore is steep to and the reef disappears, the 100 fathom line running close to the western spit of the island.

The northern part of the Mosquito Bank (the 100 fathom line), which extends nearly one hundred and forty miles to the east of Cape Gracias a Dios, is remarkably free from coral patches and banks. North of Half-Moon Reef there are only insignificant clusters of coral reefs and bars, forming the Caxones and Vivorilla Cays, to the eastward of which there are a small reef and some insignificant cays designated as the Gorda Bank.

The submarine scenery of some parts of the West Indies must be most striking. We have first the long line of steep eastern slopes of the Bahamas, with the valleys separating them, which rise abruptly from a great submarine plain, extending far to the eastward and constituting the floor of the ocean, from a depth of twenty-five hundred fathoms. This plain extends all the way from the Little Bahama Bank to Navidad, a distance of over seven hundred miles. Then follows the long, unbroken submarine slope extending off Porto Rico to the eastward of the Anegada Channel for a distance of over four hundred miles, with the remarkable sink of more than forty-five hundred fathoms in depth north of Porto Rico, one of the greatest depths as yet discovered in any ocean. Then the valley, over twelve thousand feet deep, which extends south of the smaller eastern Bahama banks, gradually lessening in depth toward the Old Bahama Channel and flanked on the southern face by the mountains of San Domingo. And finally, perhaps the most striking topographic feature of the West Indian area, the deep valley skirting the southern shore of

Cuba and extending eastward as far as Misteriosa Bank and into the Gulf of Honduras. This valley reaches to Swan Island; it is flanked on the south by the gentler slope of the eastern end of Jamaica, and the steeper lines of the western end of that island; on the northern edge rise the high mountains of the southern coast of Cuba, some of the peaks of which attain a height of over eight thousand feet. This range is continued to the westward of Cape Cruz, and its summits are the Caymans and the shoals of Misteriosa Bank. This valley is known as Bartlett's Deep: it is in many places more than three thousand fathoms in depth. The folds, islands, and banks which give the hydrography of the northern, western, and eastern boundaries of the Caribbean so varied an appearance are in striking contrast to the great sea-sunken plains which form the basin of the Caribbean and of the Gulf of Mexico.

The steep slopes off the southern coast of Cuba due to the elevation of that part of the island, as well as the slopes off the northern and southwestern shores of San Domingo, are fully as steep as any of the sea faces of the Bahama banks. If in the one case, where the coral limestones are of limited extent, we find no difficulty in interpreting the origin of this slope, we should not in the other, where the reef limestones merely form a capping to submarine folds which owe their origin to the same causes, attempt to explain its existence in any other manner.

## THE BOTTOM AND ROCKS ON THE BAHAMA BANKS.

### The Bottom.

The nature of the bottom[1] on the banks varies greatly according to the locality. In proximity to the shores of the islands, where the sea is constantly wearing away and disintegrating the æolian rocks, the bottom consists of æolian sand, varying in size according to the character of the adjacent rocks from coarse composite grains to the finest, almost impalpable powder. As we pass into deeper water,[2] away from the influences of the shore sand kept in more or less constant motion, the grains of æolian sand become mixed with fragments of corallines, or of Invertebrates which have lived upon its surface, and where corallines occur in great abundance the flat fragments of their stems often constitute the greater mass of the bottom samples. In the vicinity of coral heads the bottom is composed of æolian sand of different degrees of coarseness, more or less mixed with comminuted fragments of Gorgonians, of Millepores, and of other corals. On such parts of the banks there also occur a very considerable number of Orbitolites and other Foraminifera.. Of course, in the proximity of the edging reefs and along their faces fragments of corals, of corallines, of Nullipores, of algæ, and of Invertebrates are an important component of the bottom, the pieces of coral and of corallines often constituting by far the greater mass of the sand.

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[1] Judging from the specimens of the bottom brought up in the dredge, the action of the sea has still considerable force at a depth of nearly fifteen fathoms.

[2] By an unfortunate oversight, the coral ooze which extends only a comparatively short distance from the 100 fathom line along the line of the Florida Reefs and of the coast of Cuba is marked on the colored map of bottoms of the "Three Cruises of the Blake" (Fig. 191) as extending all the way across the Straits of Florida. The central part of the channel of the Gulf Stream should be colored to indicate the extension of the modified Pteropod and Globigerina ooze which covers so great a part of

The beaches are, according to their locality, composed either of very fine coral sand, or of coarser coral sand mixed with corallines and æolian sand, or of large pieces of corals and of other Invertebrates which become cemented together to form a breccia or a conglomerate, so that we may have bottoms composed of particles varying from an impalpable powder to coarse fragments, the components of which can readily be recognized. When a considerable amount of vegetable matter has become mixed with the æolian or coralline sand, the bottom becomes more or less sticky and marl-like, and assumes a grayish color. This is the character of a great part of the bottom on the interior of the Little Bahama Bank; while on the eastern shank of the Great Bahama Bank, and on the smaller banks extending to the eastward of it, the bottom varies greatly according to the local conditions; on the western shank of the Great Bahama Bank a large area off the west coast of Andros is covered with the "white marl" already described.

The principal coralline algæ are species of Penicillus, Acetabularia, Halimeda, and Udotea, fragments of which can readily be recognized as components of the bottom specimens wherever they grow in numbers. The decaying of other algæ which compose the flora of the bottom merely adds more or less vegetable matter to its calcareous components; the most abundant of these algæ are species of Thalassia, of Padina, Cau-

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the Gulf of Mexico and the Caribbean Sea, and which also extends over the bottom of the wider passages between the Bahamas. The so called coral ooze is in reality a calcareous mud formed of decomposed corals and corallines, consisting sometimes of very fine particles, which often accumulate along the shore line in sheltered localities, or are carried to considerable distance when held in suspension in the water along the line of currents.

lerpa, Laurencia, Blodgettia, Liguria, and Sargassum. Professor Farlow, who examined the algæ collected, notes as an interesting acquisition from the Bahamas specimens of Caulerpa Webbiana, thus far known only from the Canaries.

Dr. T. W. Richards was kind enough to have some analyses made of bottom specimens selected with regard to their locality on the banks: one specimen off the west shore of Eleuthera from two fathoms of water to represent the bottom on the interior edge of the bank; one on the middle of Salt Cay Bank, half-way between Elbow Cay and Anguila from three fathoms, and one from Exuma Harbor in two fathoms, to represent the bottom on the outer weather edge of the bank; one specimen from Bemini, in two fathoms of water, to represent the bottom on the lee side; and a sample of the white marl off Billy Island, in one and a half fathoms.

The analyses, made by Mr. Donald Churchill, show a variation of the percentage of CaO between 52.38 and 53.43, with the exception of the sample from the west coast of Eleuthera, in which the percentage is only 45.94. This bottom specimen was composed in great part of fragments of Orbitolites, with comparatively little æolian sand, while the other samples varied from the impalpable powder of which the white marl is composed to finer and coarser æolian sand, and to a bottom consisting of fragments of broken shells of Nullipores, corallines, Millepores, corals, Gorgonians, and coarse æolian sand.

The percentage of CaO (average of two analyses) in the specimens of bottom from off the west side of Eleuthera, in two fathoms, is 45.95; from the outer edge of the bank, Exuma Harbor, in two fathoms, 53.38; from the western edge of the bank, North Bemini, in two fathoms, 52.46; half-way across Salt Cay Bank, in three fathoms, 52.39.

A qualitative examination of the white marl showed a very large quantity of $CaCO_3$, a little magnesic oxide, a little ferric oxide, and a very little silica and organic matter. Five grams of the powdered $CaCO_3$ bottom lost 7± milligrams upon being washed with 200 c.c. of water. Five grams of the same were digested with 250 c.c. of sea water (from the Bahamas) for a week. Upon washing upon a Gooch crucible with 200± c.c. of water, the $CaCO_3$ was found to have lost 3± milligrams. The carbonate was tested qualitatively for sulphuric acid, which was found in small quantities. A saturated solution of gypsum in water at 20° contains about one gram of CaO per litre. Nearly four times as much dissolves in a saturated salt solution. Dr. Richards hopes to make some additional experimental trials with reference to the solubility of gypsum in sea water.

The amount of CaO in sea water from the Bahamas appears to be quite constant, as far as shown by the analyses kindly made for me by Dr. Richards. Water taken from the Tongue of the Ocean, No. 1, or from the central part of the Great Bahama Bank half-way between Green Cay and Exuma Sound, No. 2, or close to Exuma Sound on the eastern edge of the bank from the west side of Flamingo Cay, No. 3, or near the western edge of the bank south of New Providence, No. 4, showed only slight variations in the composition of the sea water. The mean of two measurements of 1,000 c.c. of sea water at 4° were as follows: No. 1 contained 0.585 gram CaO; No. 2, 0.585 gram; No. 3, 0.580 gram; No. 4, 0.588 gram.

The percentage of carbonate of lime present in the bottoms surrounding coral reefs depends in part upon the presence of magnesia or upon the admixture of decomposed vegetable or animal matter, and in part upon the amount of moisture. In districts where the coral reefs occur on shores consisting of stratified or volcanic rocks, the coral sand is also more or less mixed with particles derived from the rocks composing the basement or abutments of the reefs. In volcanic regions the limestones are often greatly modified, either by heat or by their mixture with volcanic ash. The same action was also effective in modifying the reef limestones of the dolomitic region of Tyrol. We also find in volcanic regions a proportionally larger percentage of magnesia.

A number of specimens of coral, of coral rock, and of coral beach sand, from different localities, have been kindly analyzed for me by Prof. F. W. Clark. The greatest variations in the percentage of carbonate of lime are found in the specimens from the volcanic region of the Sandwich Islands, and in the deposits of Sombrero (West Indies). The coralline bottoms and coral sands from the Sandwich Islands also contained a larger percentage of MgO than any similar bottoms from the Florida Reefs or Bahama Banks. The elevated limestones of Cuba from the Yunque are not dolomitic, and show no trace of magnesia. In the coral sand mixed with volcanic ash the amount of magnesia in one case rose to over eleven per cent.

| | CaO | CO$_2$ | MgO | Moisture. |
|---|---|---|---|---|
| Piece of Siderastrea | 55.16 | 43.74 | 0.20 | 0.54 |
| Very coarse sand, coral fragments, Tortugas | 51.52 | 41.58 | 2.08 | 3.18 |
| Finer sand, " " " . | 52.24 | 41.46 | 1.53 | 3.27 |
| Tortugas, fairly coarse sand | 51.24 | 41.07 | 2.09 | 3.57 |
| " finer sand | 51.95 | 41.53 | 1.44 | 3.07 |
| Key West, very fine beach coral sand | 49.38 | 40.39 | 1.93 | 5.12 |
| Loggerhead Key (stratified shore coral rock) | 53.54 | 43.71 | 0.78 | 0.81 |

| | CaO | $CO_2$ | MgO | Moisture |
|---|---|---|---|---|
| Salt Key Bank, oölite | 53.54 | 43.87 | 0.71 | 1.13 |
| Sombrero deposits ($P_2O_5$ 39.12) | 51.15 | 3.47 | trace | 7.55 |
| Coralline Bottom, Tortugas | 46.45 | 43.40 | 5.15 | 2.73 |
| Senote limestone near Merida | 54.87 | 43.89 | 0.64 | 0.11 |
| Diamond Head, Sandwich Islands, coral rock | 44.82 | 40.81 | 5.32 | 1.86 |
| Kohuku Bluff, “ “ “ “ | 51.09 | 43.64[1] | 2.50 | 0.79 |
| Kohuku Beach, “ “ sand | 49.34 | 44.33 | 4.60 | 0.40 |
| Honolulu Reef, coral rock | 46.52 | 40.59 | 2.45 | 2.75 |
| Prison Knob, Honolulu (elevated coral) | 52.67 | 42.81 | 0.42 | 1.24 |
| Waianea (hard ringing limestone) | 50.69 | 43.96 | 2.98 | 0.46 |
| Modern chalk, Oahu ($SiO_2$ 33.25, $Al_2O_3$ 19.13, $Fe_2O_3$ 10.71) | 11.37 | 11.09 | — | 9.84 |
| Lava soil bedded with coral near Pearl River ($SiO_2$ 46.22, $Al_2O_3$ 19.16, $Fe_2O_3$ 12.94) | 1.72 | 0.00 | 2.24 | 16.84 |
| Same from Diamond Head ($SiO_2$ 32.83, $Al_2O_3$ 12.12, $Fe_2O_3$ 11.52) | 12.20 | 11.41 | 11.70 | 5.30 |

### The Rocks of the Bahamas.

The characteristics of the æolian rocks of the Bahamas have been noted in the description of the different islands of the group. They vary from a fine-grained compact oölite to a coarse-grained rock composed either of rounded or of small angular fragments, according to the condition of the fragments of the sand from which the æolian hills were composed. These rocks vary according to the conditions to which they have been subjected, and which often greatly alter their aspect. They become more or less hardened or covered with a hard ringing crust when exposed to the action of the sea or of the rains, or to the decomposing effects of the acids generated by the decomposition of vegetable matter. Sufficient time has not elapsed since my return from the Bahamas and Bermudas to report more in detail regarding the composition of the rocks and bottoms of these regions. But I hope to return to this subject, and present the results of the examination of the rocks now making by Professor Wolff.

## SOME RECENT VIEWS ON THE THEORY OF THE FORMATION OF CORAL REEFS.

It may not be out of place to pass rapidly in review some of the points relating to the theory of the formation of coral reefs which have been brought forward in the discussion of the subject in the new issue of Darwin's Coral Reefs, edited by Professor Bonney;[1] in the interesting review by Dana of the whole subject in the American Journal of Science (1885, Vol. XXX. pp. 89, 169) and in the new edition of Dana's Corals and Coral Islands (New York, 1890), with the Appendix on the Sandwich Islands;[2] and in the essay by Dr. Langenbeck[3] on the Theories of the Origin of Coral Islands and Coral Reefs.

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[1] Trace of organic matter.

In this chapter I shall bring together and discuss only such questions as have naturally been suggested by my explorations of the Bahamas, the Florida Reefs, the Cuban elevated reefs, and the reefs of the Windward Islands. Minor points will be found referred to in other places of this report, and in the articles of the Duke of Argyll and of Professor Huxley, as well as in the more recent communications in "Nature" and elsewhere by Murray, J. C. and G. C. Ross, Irvine, Harrison and Browne, Bourne, Guppy, Hickson, Captain Wharton, Studer, Ortmann, Dall, Balfour, H. O. Forbes, Supan, Perrier, Heilprin, Captain Moore, Sluiter, Walther, Lendenfeld, Kent,[4] and many others, as well as the Presidential Addresses of Sir Archibald Geikie and of Professor James Geikie at Edinburgh in 1883 and 1892.

While it is undoubtedly true, as Professor Bonney states, that many of Darwin's critics may have perused his book with overmuch haste, yet he must admit that when explorers examined the coral reefs of districts which apparently had nothing in common with coral reefs formed in areas of subsidence, it was most natural that they should seek some other explanation of their formation than that suggested by Darwin, and thus call upon factors which he had relegated to a subordinate value. The want of unanimity among the opponents of the Darwinian theory of the formation of coral reefs has, it seems to me, nothing to do with the question whether Darwin is right or not. It merely shows that there are many points of difference which are more or less apparent in the various districts examined by recent writers on coral reefs, and that perhaps the problem of their formation is not quite so simple as the upholders of the subsidence theory would have us believe.

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[1] The Structure and Distribution of Coral Reefs, by Charles Darwin. Third Edition. With an Appendix by Prof. T. G. Bonney. London, 1889.

[2] See also A. Agassiz, Bull. Mus. Comp. Zoöl., Vol. XVII. No. 3, p. 121, 1889, "The Coral Reefs of the Hawaian Islands."

[3] Die Theorien über die Entstehung der Koralleninseln und Korallenriffe und ihre Bedeutung für Geophysischen Fragen. Von Dr. R. Langenbeck. Leipzig, 1890.

[4] Kent, in his Monograph of the Great Barrier Reef of Australia, has added comparatively little to our knowledge of the theory of its formation. "He looks for the conditions of subsidence which have made the formation of the Great Barrier Reef possible in the former undoubted connection of Australia with Tasmania and New Guinea; and if that is not satisfactory, he is quite ready to call upon a still greater subsidence of the Australian continent as shown by its presumed connection with New Zealand. If, as is probable, and as Mr. Kent suggests, the Great Barrier Reef existed as a narrow fringing reef in the late Tertiary, there has elapsed more than ample time also for its transformation into the Great Barrier Reef of to-day from other causes than those called upon by him. The Great Barrier Reef has entirely obliterated the Australian coast shelf itself, and it may have found upon that all the conditions of depth for the vigorous growth, both vertically and laterally, of the original insignificant fringing reef of the northeastern coast of Australia." — Nation, No. 1463, July, 1893.

The disadvantages of a discussion of the theory of the formation of coral reefs by one who has not faced the problem in the field are apparent in the essay of Dr. R. Langenbeck. It undoubtedly is a most useful summary, and, while the writer has endeavored to retain an impartial attitude, his views naturally do not carry much weight, based as they are only upon cartographic knowledge, and consisting in great part of special pleading in favor of the theory of subsidence. His essay does not seem to me to have the importance assigned to it by Huxley in his discussion of the article on "A Conspiracy of Silence,"[1] by the Duke of Argyll. This and similar essays can give us only interesting speculations, of little value except when tested by observations.

Dr. Langenbeck has been unfortunate in the exposition which he gives of the Florida and West India reefs. His description of the reefs of Cuba and of the Bahamas differs greatly from that given by the writers from whom he has taken his data. But he is the first writer on the theory of reefs who, while of the opinion that the theory of Darwin is the only one which can explain the formation of atolls in the extensive tracts of the Pacific where atolls are so numerous, yet acknowledges that there are extensive districts in which the formation of reefs has not been influenced by subsidence. This was the principal point at issue between the earlier opponents of the theory of subsidence. Subsequent investigations in the Pacific and elsewhere have shown most clearly that the reef problem is a complicated one, and that we have not heard the last word on the subject. As far as the formation of many of the Pacific atolls is concerned, either they have been formed by subsidence, and owe their origin to causes different from those which in the West Indian and other districts have formed atolls upon comparatively shallow bases, or they have been formed by the same causes to which the latter owe their shape independently of subsidence, or we may further assume that atolls can be formed in regions of subsidence independently of the subsidence, as well as in regions where no subsidence has been observed.

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[1] I am unable to understand the statement of Professor Heilprin (The Bermudas, p. 21) regarding the authority of "A Conspiracy of Silence." It is most extraordinary if, as is stated by Heilprin, the "younger school of geologists" have pinned their faith to the statements of its author and have chosen for their leader one who has never made any original observations on the subject of coral reefs. The great majority of recent observers of coral reefs have stated that the generally accepted theory of their formation was not applicable to the particular district they examined. Each has endeavored to give an explanation of the facts, and they have not "pinned their faith to any standard bearer," or to any theory, or to any leader, or to any creed.

Darwin, and after him Langenbeck, as well as other writers on the West Indian coral reefs, speak of the "extensive banks of sediment which have been heaped up along the whole north coast of Cuba by sea currents." I find it difficult to account for the origin of such a belief. That a great part of the food supply of the animals living upon the banks has been brought to them by sea currents is self-evident, but the mass of sediment so conveyed is insignificant as compared with the accretions to the banks due to the accumulation and cementing of the carcasses of the Invertebrates living upon them. There is, it is true, a long stretch of sand reefs and islands all the way north from Key Biscayne to beyond Cape Hatteras, but these have nothing in common with the limestone barriers forming the basement of the Florida, Cuban, and other West Indian (Mexican and Caribbean) coral reefs.

I am surprised that Professors Dana and Bonney should both speak so strongly against the statement of Murray, that there are known numerous submarine elevations, mountains rising from the general level of the ocean bed, which may serve as the foundation of a coral reef. Surely, we know as yet too little of the hydrography of the Pacific to sweep away the statement with the suggestion "that such a thing may occasionally occur."

Professor Dana, who has made such a thorough examination of the Feejee Islands, considers the conditions of the coral reefs of the islands of the group as admirably illustrating Darwin's theory of the formation of barrier reefs and of atolls. In spite of the general aspect of a sunken continent made by the Feejee Archipelago, it is no proof that the reefs owe their present condition to subsidence. It seems to me that the illustrations he brings up merely emphasize the great diversity of substructure of banks and islets and of large islands in the Feejee Islands upon which fringing, barrier reefs or atolls might be found; just as in the Windward Islands and the Virgin Island Bank we find all possible conditions of elevation, from islets at the sea level, or sunken banks, to islands with peaks of over four thousand feet, at the base of and around which barrier and fringing reefs may be formed, or crescent and horseshoe-shaped reefs might grow.

The somewhat insignificant coral reefs of the Eastern Pacific, as far as known, occur upon volcanic islands. Those of the Sandwich Islands and the unimportant coral patches of the Galapagos grow upon a basement of volcanic origin, while the only atoll of the Eastern Pacific — Clipperton Rock, off the Mexican coast — holds to its trachytic nucleus much the same relation which some of the reefs of the Caribbean hold to the volcanic peak they surround.[1]

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[1] The absence of extensive coral reefs off the west coast of Tropical America is probably due to several causes, the most important of which as regards the mainland is the large amount of mud brought down the shore mountain slopes during the rainy season. Similar conditions exist along the shores of the Galapagos, where corals are formed merely in patches, as along the coast of the mainland, in addition to whatever influences detrimental to their growth may be due to volcanic action. (See Dana, Corals and Coral Islands; Pourtalès, Am. Journ. Sci., 1875, Vol. X. p. 282; and A. Agassiz, Bull. Mus. Comp. Zoöl., Vol. XXIII. No. 1, 1892.)

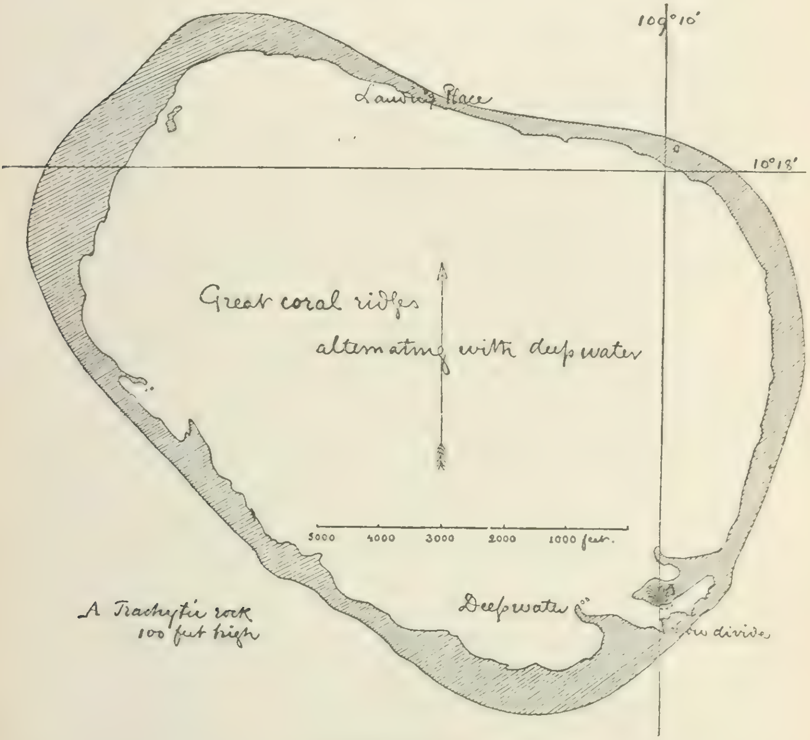
It is interesting to add here some notes relating to Clipperton Rock, which prove the existence of an atoll on the borders of the Panamic region, seven hundred miles southwest of Acapulco. I am indebted to Professor George Davidson of the U. S. Coast Survey for a sketch of Clipperton Island by Carl C. Jensen, made in 1893, as well as for a specimen of the rocky nucleus. The latter was examined by Professor J. Eliot Wolff, who reports it to be "a volcanic rock with typical trachytic structure, of the same general class as the rock from the hospital quarry at Panama."

The description drawn up from the notes and chart he kindly sent me agrees in the main with the one given by Lieutenant Griswold, and published by W. H. Pease in the Proceedings of the California Academy of Natural Sciences (1865, p. 199).

Clipperton Rock was seen from the northeast by Sir Edward Belcher in 1839, and described by him as a coral lagoon island with two entrances, both on the weather side. It was, according to W. H. Pease, visited in 1861 by Lieutenant Griswold, who landed upon the island, and says in his Journal: "It is girdled by a broad barrier of coral about fifteen feet above the level of the ocean. There is no entrance to the lagoon. The water inside is fresh and potable; it is slightly brackish. . . . The rock is a ragged pile of volcanic formation, on the south end of the island. . . . The highest pinnacle of the rock is about 120 feet, and it covers about two acres. It stands on the edge of the lagoon, or rather within it. . . . The lagoon is a quiet fresh-water pond about two miles long and one broad, with a long spit of mud running out into the middle of it, but elsewhere of a light green color which seemed to indicate a considerable depth. [Light green does not in coral districts indicate a considerable depth; on the contrary, it may indicate a depth of six to seven fathoms at most. — A. Agassiz.] The shores are abrupt. . . . I did not find the least sign of vegetable life upon the island."

Mr. Jensen says there are no trees on the island. It is surrounded by a reef of coral over which the sea continually breaks. Outside of this unbroken reef the bottom deepens rapidly, and vessels must anchor in not less than fifty fathoms of

In the West Indies, beginning with the Bermudas, is the mass upon which the so called atoll has been formed, — an island rising out of a water. Best boat landing on the north side of the island. On the chart "Deep water" is marked in the atoll to the westward of the trachytic rock near the southern face of the island. "Great coral ridges alternating with deep water" is the legend of the central part of the lagoon. A few insignificant islets are mapped in the lagoon near its northwest face. The atoll is pear-shaped, its axis running southeast to northwest; its greatest breadth is over one and a half miles, and its length more than two.


109°10'
Landing Place
10°18'
Great coral ridges
alternating with deep water
5000 4000 3000 2000 1000 feet.
A Trachytic rock
100 feet high
Deep water
w divide

CLIPPERTON ISLAND.

On Mr. Jensen's chart the island is represented as a narrow ring of coral rock surrounding the lagoon. This dry belt is nowhere more than seven hundred feet wide, except to the southwest of the trachytic rock, where there is a short spit extending into the lagoon, the point of which is perhaps fifteen hundred feet from the outer edge of the island. At several points the coral rock belt is not more than two hundred feet wide, and along the greater part of the southwest coast it varies between four and five hundred feet in width. A similar narrow stretch of perhaps three quarters of a mile extends along the north side. This connects the two broader shore tracts of the eastern and northwestern parts of the island.

depth of two thousand fathoms. Has that atoll been formed by its subsidence? If so, we should have a great oceanic depression in the vicinity of the Bermudas. We know nothing of the hydrography which does not indicate that the mass underlying the coral reefs rises abruptly from the ocean floor; as to what height it originally rose, we have no data.

Examine next the submarine range of the Windward Islands, with its varied depths, of which the islands beginning at the Grenadines and ending with Saba are the exposed summits. Note the gradual widening of the bank as we go north, and finally reach its widest part, upon which are situated islands of recent limestone which have risen from a comparatively shallow bank, while farther south the recent limestones are limited to the Basse Terre of Guadeloupe, or to the fringing reefs of Martinique, St. Vincent, Dominica, and the Grenadines.

Isolated from the other islands in the line of the submerged chain, we have Sombrero, a recent limestone island, while Bird Island and the Barbados are the summits of two isolated banks, both of different heights. Surely, we have in that submarine chain a sufficient variety in the depths of the bank to account for the irregular position of the limestone deposits now going on, and a sufficient number of points which have reached by elevation the depth necessary and favorable for the growth of coral reefs. Some of the localities have been elevated above that level, as Barbuda, Antigua, Anguilla, Barbados, and Basse Terre, while at other points — as Martinique, St. Vincent, and the Grenadines — the fringing and barrier reefs are still in full activity.

The Saba Bank, the bank upon which have risen Antigua and Barbuda, and the bank within which are found Anguilla and St. Bartholomew, are extensive shoals compared with the dry land of the island. Upon the Mosquito Bank also numerous coral reefs are found, rising from varying depths, similar to those of the Yucatan Bank.

Between the Mosquito Bank and Jamaica are a number of banks within the 100 fathom line, some of which, like those surrounding St. Andrews or Old Providence and the Morant Cays, have come to the surface; while others again, like the Serrana, Rosalind, Serranilla, and Pedro Banks, have not reached a depth at which corals can begin to grow, or have sunk below it. This gives in such a limited district as the Caribbean Sea proper a sufficient number of instances of submarine banks reaching all possible levels, some of which are in localities where corals have developed to form fringing or barrier reefs, others where the corals are reduced to irregular patches, and others where, the conditions for their growth not being favorable, the banks are free from corals, their surface being more or less disturbed by the action of the trades, thus choking off the growth of any delicate marine forms. This leaves out of notice the great number of banks of the Bahamas, that of the west side of Florida, of the banks extending from Cape Sable to the Tortugas, of the banks to the south of Cienfuegos, extending from the Isle of Pines to Cape Cruz, and, finally, the bank to the eastward of Porto Rico upon which rise the Virgin Islands. Corals flourish upon all these banks; they form fringing and barrier reefs, and in a few instances atolls, such as Alacran, the Hogsty Reef, and the atolls of the Mosquito Bank, which I have not, however, examined myself. We cannot assume that corals are only to grow where the base has reached the proper depth during a period of subsidence, while they are denied that privilege where the right depth has been reached in a period of elevation.

There is no greater distance between the elevated reef of the south shore of Cuba and the fringing reef of parts of San Domingo and Jamaica than there is between those of the north shore of Cuba and the barrier reef of the Florida Keys. The time at which the reefs of different areas in the West Indies were elevated need not necessarily have been synchronous, nor should we expect this in a district where volcanic agencies have been at work on so great a scale. This would go far to account for the great diversity of coral reefs we meet with in the West Indian district within comparatively short distances.

In fact, what I have seen so far in my explorations of the coral reefs of the West Indies would show that wherever coral reefs occur, and of whatever shape, they form only a comparatively thin growth upon the underlying base, and are not of great thickness. In Florida they rest upon the limestones which form the basis of the great peninsula. On the Yucatan Bank they are underlain by a marine limestone. In Cuba they abut upon the Tertiary limestones of its shores. Along Honduras, the Mosquito Coast, and the north shore of South America, they grow upon extensive banks or shoals, parts of the shore plateau of the adjoining continent, where they find the proper depth.

Similarly, along the shores of the Greater Antilles they are found rising from depths suitable to their growth upon the shore plateaus, as well as upon the peaks and summits of submarine ranges which either come to the surface or approach it. Round the Windward Islands they thrive upon the banks which surround them. But in neither case have they played any important part in the building up of the banks or of the shore plateaus upon which they occur. Upon the Bahamas and Bermudas the corals now growing form a thin veneer upon the æolian rock ledges, the remnants of the vanishing land formed from a coral reef which must have flourished at the beginning of the present epoch.

But Dana himself has even more distinctly and emphatically than any other writer stated the objections to the general application of the theory of subsidence for the formation of barrier reefs. In "Corals and Coral Islands," he says (p. 347): "The amount of subsidence determines in some cases the distance of barrier reefs from shore; but it by no means accounts for the difference in their extent in different parts of a single group of islands. Indeed, if this cause be considered alone, every grade of extent, from no subsidence to the largest amount, might in many instances be proved as having occurred on a single island. Of far greater importance, as has appeared, is the volcanic character of the land." The remainder of the paragraph quoted above, describing the relations of volcanoes and of zoöphytes as the land-making agents of the Pacific, seems hardly consistent with the subsidence theory.

Many of the observations made on elevated coral reefs do not distinguish between the elevation of a thin mantle on a slope to a certain height, and the thickness of the reef itself. Furthermore, in such a difficult problem only the observations of trained observers can be of value. Many of the data, and even many of those quoted by Dana, are the records of merely casual observations of individuals with little or no experience in this field.

The island of Lafu, one of the Loyalty group, the geology of which has been described by the Rev. W. B. Clarke,[1] is one of the few elevated coral islands of which we may feel certain that the highest points, two hundred and fifty feet above the sea, are covered by an elevated coral reef, the elevation being connected in that case, not with volcanic action, but with the elevation of the adjoining island of New Caledonia. Subsequent investigations of the Loyalty group by Balansa[2] and Chambeyron have shown that other islands of the group are covered by elevated coral reefs. Ouvea attains a height of a little over fifty feet, with an interior lagoon; and while Lafu shows three terraces, the neighboring island of Mari has five distinct terraces, attaining a height of one hundred meters, with a nucleus of trachyte.

From the interesting accounts given by Captain Chambeyron, in his "Note relative à la Nouvelle Caledonie,"[3] we can see how much remains

[1] Proc. Geol. Soc. London, 1846, p. 61.

[2] Bull. de la Soc. de Géog., Vol. V. p. 521, 1873.

[3] Ibid., Vol. IX. p. 566, 1875.

to be learned regarding the barrier and fringing reefs and the great lagoon of New Caledonia. We need additional information regarding the thickness of coral reefs to complete the evidence of their great thickness as due to subsidence. The thickness of such elevated reefs as may without question be considered true coral reefs is not as great as it has been supposed by various observers (see Dana, p. 274). The more recent examinations of the thickness of the elevated coral reefs in the Solomon Islands by Guppy, in the Barbados by Harrison and Jukes-Browne, in Cuba by R. T. Hill[1] and myself, all tend to prove that elevated coral reefs nowhere have attained a thickness of more than two hundred to two hundred and fifty feet. This shows that a thickness of two thousand feet observed in Cuba by Professor O. W. Crosby, of twelve hundred feet near Matanzas reported by myself, and of two thousand feet of the white limestones of Jamaica, are not the thickness of coral reef builders, but of marine limestones of very different character; and that the true reef-building corals have merely built a sheet of moderate thickness upon these older limestones, which have been mistaken for limestones built up by reef-building corals. The reefs of the weather side of the island of Oahu form quite a thin sheet overlying the volcanic rocks.

Similar conclusions have been reached by the recent examinations of dolomitic limestones, which are of great thickness (over two thousand feet), and were until recently unhesitatingly considered as coral reef limestones. They have now been shown by Miss Ogilvie and by Rothpletz to be marine limestones, while the true coral reef builders formed deposits of very moderate thickness, a coral growth, as it were, not thicker than one hundred and fifty feet. It is very evident that, in the examination of the coral deposits of former geological periods, great care must be taken to distinguish between coral growths forming a comparatively thin veneer and marine limestones of great thickness in which corals are occasionally found.

The discussion of Langenbeck on the coral reefs of former geological periods is subject to revision after a re-examination of the localities, in accordance with the recent explorations of the dolomite region, and of our more accurate knowledge of the distribution and thickness of the West Indian reefs. The fossil reefs of the Jura were among the earliest known. Attention was first called to them by Thurman (1859) and Gressly (1860), but they have not been examined recently with reference to the points now in dispute regarding the formation of coral reefs.[2]

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[1] Amer. Journ. of Science, September, 1894.

[2] See Zschokke, F. Die Korallenriffe im Schweizerischen Jura. Aarau, 1890.

In no case has Thurman or Gressly observed ancient coral reefs of very great thickness (one hundred meters) at all to be compared with the thickness claimed for modern reefs by Darwin and Dana (two thousand feet).

The evidence brought forward from the existence of recent limestone beds of great thickness in Java and in the Philippines and other localities, to which reference has been made as proof of the great thickness of coral reefs, must be taken as subject to modification. One of the most interesting of the fossil coral reefs is the atoll of Benguet, in the island of Luzon, mentioned by Drasche.[1] It has walls of five to six hundred feet above the valley, which itself is about four thousand feet above the sea level. The surface of the limestone is filled with red earth, often several feet in thickness. The limestones, unlike coral reefs, are distinctly stratified. The corals and other fossils belong to genera which still occur in the Indian Ocean of to-day, so that the limestones of the atoll of Benguet and of Northern Luzon belong to the most recent formations of the island, and from their description differ greatly from the coral reef limestones of to-day.

Richthofen's[2] theory that the Schlern Dolomite was a coral reef was adopted in the main by Mojsisovics,[3] and their views, although opposed by Gümbel,[4] have received general recognition until comparatively recently. Miss M. M. Ogilvie, in the Geological Magazine for January and February, 1894, perhaps first called attention to the peculiar occurrence of the so called coral reefs in the Dolomites.

In the interesting account of coral in the Dolomites of South Tyrol by Miss Ogilvie an entirely new view is taken of the reef-like appearance assumed by the dolomitic massifs, which she traces to the movement of the rocks in Tertiary times, and to the variation in the character of contemporaneous Triassic deposits, her conclusions being that, "as far as positive evidence goes, the coral rocks of South Tyrol in the Wengen and Cassian period are not the majestic massifs of Dolomite, but much less obtrusive lenticular masses of limestone," the "Cipit limestones."[5] Miss Ogilvie has shown in the diagrams I.–IV., on Plate II., (*a*) that coralline "Cipit limestone" and coral Dolomite form comparatively small thicknesses of interbedded rock, and not the main body of the mountain masses; (*b*) that corals began to grow in Wengen time on a submarine volcanic ridge on the northern edge of a great area of subsidence, and travelled northward and inward in Cassian time; (*c*) that extensive banks of coral were found in scattered localities during the Raibl period of shallower water and Dolomite deposit. And the final paragraph of the paper contains the following statement: "My special survey in a part of the district seems to me to justify, without doubt, the position of those authorities who have contended that the immense thicknesses of 'Schlern Dolomite' rock were an ordinary marine deposit, and not 'coral reefs.'"

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[1] Drasche, R. von. Fragmente zu einer Geologie der Insel Luzon. Wien, 1878.

[2] Geognost. Beschreib. der Umgegend von Predazzo in Süd-Tirol. 1860.

[3] Die Dolomit Riffe v. Süd-Tirol u. Venetien. 1879.

[4] Sitzb. d. Akad. d. Wiss. München. 1873.

[5] See Plate II., February number of the Geological Magazine for 1894, and the figure on page 53 of the same number.

In the descriptions of the Dolomitic region by Richthofen and by Mojsisovics, "the thick dolomitic massifs of Schlern Sella." etc., were regarded as dolomitic reefs, though they have originated as marine deposits, and not coral reefs. "The Wengen and Cassian coral reefs of Gröden, Ennenberg, and Upper Fassa have remained, with but rare exceptions, limestone. The actual thickness attained by the individual lenticular coral reefs or the coral banks is in no case very great, seldom more than one hundred and fifty feet, and usually much less."

Finally, Rothpletz,[1] after a thorough examination of the field, comes to the following conclusion: —

"Wir können also die zu Beginn dieses Capitels aufgeworfene Frage, ob der Schlerndolomit eine Korallenriffbildung sei, jetzt mit einem entschiedenen Nein beantworten, so bald man die Frage in dieser Allgemeinheit noch stellen will. Die bisher besprochenen reinen Kalk- und Dolomitmassen der oberen Trias sind allerdings vorwiegend organogenen Ursprungs und verdanken ihre Massigkeit dem Wachstum von Thieren und Pflanzen in wenig tiefen oder sogar seichten Meerestheilen. Aber Korallen haben dabei durchaus keine besonders hervorragende Rolle gespielt, wenn schon sie stellenweise wahre Rasen bildeten und wohl auch zu kleinen echten Riffbildungen geführt haben mögen. An den meisten Orten hingegen treten sie anderen Thieren und den Pflanzen gegenüber so sehr in den Hintergrund, dass wir sie nur als einen untergeordneten Bestandtheil der Fauna bezeichen können. Viel bedeutsamer werden sie statt dessen mancherorts in den Cassianer und Raibler Schichten. Es ist bezeichnend genug, dass der Schlerndolomit des Schlernes selbst nur sehr wenige Spuren von Korallen aufweist, während die wenig machtigen Dolomitplatten der Raibler Schichten auf dem Schlernplateau, also unmittelbar im Hängenden des letzteren, geradezu aus Korallen zusammengesetzt sind, so dass sie als wahre Korallenrasen bezeichnet werden müssen. Die Dolomitisirung des Gesteines hat dieselben keineswegs verwischt und unkenntlich gemacht. Wir können aber auch da nicht von eigentlichen Riffen, sondern nur von Rasen sprechen, den ihre Höhenentwickelung ist nur eine sehr geringe. . . .

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[1] Ein Geologischer Querschnitt durch die Ost-Alpen, p. 67. Stuttgart, 1894.

"Soll nun aber für den Schlerndolomit wenigstens der Name 'Riff' beibehalten worden, wofür neuerdings auch Suess[1] sich ausgesprochen hat? . . . Das wird von der Definition abhängen, die man dem Worte geben will. Versteht man darunter steil und hoch vom Meeresboden aufragende Massen, etwa wie die Koralleninseln des Stillen Oceans, dann passt der Name für die Ost Alpen ganz und gar nicht. Begreift man darunter aber auch die submarinen, organogenen Plateaus des Golfes von Mexico und die Dacia-Bank der Tiefsee, dann liesse sich der Name 'Dolomitriff,' wohl auch fernerhin auf die Alpen anwenden, doch musste vorher eine entschiedene Umprägung dieses Gliedes unseres Wortshatzes vorgenommen werden."

I do not mean in any way to deny the possibility of the formation of marine limestones by subsidence. But I must also call attention again to their formation at great depths by accretion, and to the fact that true coral reef builders have as yet been shown positively to attain only a moderate thickness.

The difference in the steepness of the slope of the Florida Charts off the Florida Reef and that of the steep submarine slope of the Eastern Bahamas off the edging reef, I believe, can be explained on the supposition that the Eastern Bahamas are a series of more or less disconnected summits, with slopes no steeper than those of the volcanic Windward Islands to the south of them. In the one case, the Florida reef is the belt edging a gentle slope in depths of from four to fifteen or sixteen fathoms. In the other, the edging reef of the Bahamas is a similar belt limited to the same depths on the brink of a steep slope. The structure of the coral reef and its bathymetrical range are in neither case affected by the nature of the underlying rocks, or by the angle of their slopes beyond the bathymetrical range of the corals.

Professor Dana himself, when speaking of the limited thickness of the elevated coral reefs of the Solomon Islands described by Dr. Guppy, says (Corals and Coral Reefs, p. 291): "Such observations have great interest, but they only prove that in coral reef seas corals will grow over any basis of rock that may offer when the water is right in depth and other circumstances favor. . . . They are not evidence against the subsidence theory, but simply local examples under the general principle just stated." It seems to me that in the first part of the passage quoted Professor Dana grants the principal factors which have been advanced in opposition to the universal application of the Darwinian theory of coral reefs. The objections to it from this and that quarter have little by little circumscribed the area within which it is applicable. It is not applicable to the West Indian and Caribbean Sea reefs. It does not hold true for the Bahamas or Bermudas any more than for Cuba or Florida. It does not hold for the Sandwich Islands or the Galapagos. It has not been accepted by Semper, by Rein, by Murray, by Bourne, by Guppy, nor by others who have in recent years examined many of the localities which are considered by Dana and Darwin as typical of the subsidence theory.

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[1] Antlitz der Erde, Bd. II. p. 331, 1888.

Perhaps one of the best sections of coral reef rock and limestone is that given by Julien,[1] as far back as 1867, in his description of the geology of Sombrero, W. I. The beds examined by him vary in thickness between thirty-three and sixty-six feet. From his description of the key as an atoll I imagine it must resemble either Hogsty Reef or some of the smaller pseudo-atoll banks of the Bahamas, only it has been elevated about forty feet. Some of the beds are separated by a thin layer of limestone differing from the preceding.

The formation of hills of nearly four hundred feet in height, in a district showing a probable subsidence of at least two hundred and fifty or three hundred feet, shows very plainly how a limestone bed of that thickness may have been formed from a coral reef flourishing at the time when the beach which bordered the æolian islands was at least two hundred feet higher than the present beaches on the Bahamas. It is not probable that during the period of subsidence the reef kept up its growth with sufficient vigor to add to the material which helped to build the æolian hills now disappearing before the action of the sea. On the contrary, we can only imagine such high æolian hills as those of the Bahamas to have been formed in a period of rest, during which the great beach of the then existing reef constantly supplied fresh material to be changed by the surf and the winds into sand for the heaping up of sand dunes. They could not be formed in a district of subsidence unless the subsidence was slower than the rate of growth of the corals, which is not the case in the Bahamas, as the reefs of to-day, even when they come to the surface, are not the sources from which the material for the great dunes of the Bahama Islands is derived.

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[1] On the Geology of the Key of Sombrero, W. I., by Alexis A. Julien, Ann. Lyc. of Nat. Hist. of New York, Vol. VIII. p. 251.

How far formations similar to those of the Bahamas occur in districts where there are coral limestones of considerable thickness, and where their original structure can no longer be detected, is an open question. There are groups of islands in the coral reef districts of the Pacific which from their resemblance to the Bahamas it is interesting to compare with them. I refer specially to the Maldives, to the Louisiade Archipelago, and to the Keeling Islands. The explanation which Darwin gives of the dissevermeut of the larger Maldive atolls, that the smaller ones have been formed during subsidence by a process of which traces can be detected in the northern part of the group, does not seem natural. The sunken coral reefs of which we have surveys show no such method of formation, while, on the contrary, banks of which the depth is somewhat varied, forming more or less irregular knobs or folds, could give a suitable substructure for the growth of irregularly shaped atollons such as constitute the Maldive Archipelago and the Mahlos Mahdoo atolls. We may compare with these atolls the circular reefs of the Mosquito and Yucatan Banks, which have formed wherever the conditions of depth and currents and configuration of the bottom have been favorable, in the midst of other irregularly shaped patches of corals, many of which are of considerable extent. The similarity of the eastern and western ranges of land of the Great Bahama Bank to the distribution of the atollons on the opposite sides of the Maldive atoll group has been suggested by Professor Dana; but while this is marked, the structure of the islands in one case and of the atolls in the other is, as I have shown for the Bahamas, very different. The similarity of the Bahamas to the Louisiade Archipelago suggested by Dana does not seem to me so well established. In the latter we have high islands of older rocks, and upon the edge of the plateau surrounding them barrier reefs have developed; while in the former we have a fringe of islands of æolian origin edged by a barrier reef.

In the account which Dana gives of the breaking up of the Maldive group into an archipelago of atolls, and of the Louisiade Archipelago, there is nothing clearer than that subsidence has taken place so as to bury all the high land of the archipelago, but the connection between the subsidence and the growth of the atolls and barrier reefs of these archipelagos is not so apparent. That there are submerged banks, such as the Great Chagos Bank, the Macclesfield and the Tizard Banks described by Captains Wharton and Aldrich, seems to me to show the impossibility of the synchronism of the rate of subsidence of a district with the rate of growth of its coral reefs. Off the west and northwest coasts of Australia, to the north of Houtman's Abrolhos there are extensive coral reefs surrounding adjoining islands and skirting the shores of the Australian continent. From their appearance on the Hydrographic Charts they bear a certain resemblance to the reefs of Yucatan, Honduras, and the Mosquito Coast, extending as they do out on the comparatively shallow continental platform of that part of Australia.

One cannot fail to be struck with the general resemblance of the Keeling atoll described by Darwin, and of which a chart is given by Guppy in his article on the Cocos-Keeling Islands in the Scottish Geographical Magazine for June, 1889, to some of the smaller of the Bahama Banks. The filling up of the interior lagoon from the sand driven in through the narrow and shallow passages between the islands edging the bank, and perhaps also from the disintegration of the islands themselves, will in time produce, as suggested by Guppy, a bank, the interior of which will be entirely choked by sand, while corals will continue to thrive in the northern part of the lagoon in numerous patches, much as they do in the Bahamas, where their growth is not affected by the movement of the bottom, or by the sand held in suspension during heavy weather.

The sunken banks of the Bahamas, the Navidad, Silver, and Mouchoir Banks, remind us of the Great Chagos Bank, although there is no evidence to show that these banks owe their peculiar shape to the growth of corals due to subsidence, but merely that by subsidence what was once a flourishing coral reef edging a marine bank is now by subsidence left at a depth at which corals can no longer thrive, while they still flourish and grow on the edges and interior floors where the subsidence has not been great enough to sink that part of the bank to as great a depth, or in other localities where little or no subsidence has taken place.

The Bahamas can hardly be said to have lagoons in the sense in which we understand an atoll lagoon. With the exception of the lagoon of Hogsty Reef, the lagoons of the Bahamas are either huge sinks or sloping faces extending from the inner side of islands on the edge of the banks towards their open side, or they are small salt sinks like the lakes of New Providence, the lagoon of Watling, and the many salt ponds existing on Long Island, on Inagua, on Grand Turk Island, and others.

On the Great Bahama Bank the only sinks which are enclosed by higher banks are the extensive depression between New Providence and Eleuthera, with a greatest depth of six fathoms near Eleuthera, and the two to the west of the line of cays between Highborn Cay and Harvey Cay, with a maximum depth of four and a quarter fathoms. On the

Little Bahama Bank are two depressions, one to the north of Little Abaco, the other to the south, with a maximum depth of three and three quarters fathoms. These sinks are depressions in the general topography of the banks, and have no definite relation to the islands and to their edging reefs. The slopes to the west of Cat Island and of the open banks, such as the Crooked Island, the Caicos, and Turk's Island Banks, are very gradual until they reach the edging coral reef in from four to six fathoms, whence the pitch is more rapid and quite sudden from the 20 fathom line to the 100 fathom line. There is nothing on the Bahamas which exactly corresponds to the sounds of the Bermudas, such as Harrington Sound, Castle Harbor, and the Great Sound, the land which once may have fringed the greater sinks on the Bahamas having disappeared by erosion, only flats of a more moderate depth indicating its former existence.

As is well known, a depth of fifty to sixty fathoms has been assigned to some of the lagoons in the Maldives, of twenty-five fathoms at Keeling Island by Darwin, and of twenty fathoms at Matilda atoll. In the composite atolls, like those of the Mahlos Mahdoo atoll, and other of the Maldives, the depth in the smaller atollons is stated by Darwin to be not more than five to seven fathoms, while the depth of the greater lagoon — of the bank itself — is sometimes as much as two hundred and fifty to three hundred feet. May this not be due to causes similar to those which in the Bermudas have formed the sounds, attaining a depth of nearly sixteen fathoms, and in the Bahamas have formed deep channels between adjacent but more distant banks and islands? Are the atollons perhaps, only on a larger scale, such formations as the Serpulæ reefs occurring off the south shore of the Bermudas,[1] which are purely mechanical structures, and in the formation of which the Serpulæ or corals in the case of the Maldives and Mahlos Mahdoo atoll have had but a limited share?

The islands and islets of the two archipelagos named may be only the summits of a bank of very irregular outline, upon which corals have established themselves. Subsidence has taken place there to a very considerable extent, as stated by Darwin, but the position of the corals and the shape and distribution of the reefs have only been affected in a limited manner by it and are not due to it any more than in such localities as the Bermudas and the Bahamas. The depth between Horsburgh atoll and the southern end of the Mahlos Mahdoo atoll (over two hundred fathoms) is no more surprising than the great depth of the channel between the Mira por vos Bank and Crooked Island Bank, or in the passage between the outlying banks to the south of the Bermudas.

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[1] A. Agassiz, Am. Journ. of Science, June, 1894.

Granting that the deep channels have been formed by subsidence, it does not follow that the present distribution and existence of the corals on the summits of the banks is due to the same cause.

In fact, we may apply, only inverting the argument, the reasoning of Professor Dana against a theory of elevation as explaining the origin of barriers and atolls: "Coral reefs may, like sea beaches, be made at different heights on the slopes of rising land; but this is not the result of elevation, which is implied; for barrier reefs and atolls are the objects whose origin is to be accounted for." Substitute subsidence for rising land, and remembering that reef corals will not grow at a greater depth than twenty fathoms, we eliminate subsidence as a factor, unless we are prepared to accept and imagine a synchronism between the growth of corals and subsidence in a great number of the districts in which they flourish, — of which we have no proof.

# INDEX.

The following references to the Charts of the U. S. Hydrographic Office (H. C. No. . . .) and to those of the Hydrographical Office of the Admiralty (A. C. No. . . .), give the numbers of the charts relating to the Bahamas, to Cuba, to the Gulf of Mexico, to the West Indies, and to the Caribbean, which have been consulted during the preparation of this Report on the Cruise of the Steam Yacht "Wild Duck." In the Introduction, see page 15, reference has been made to the general charts covering the region explored by the "Wild Duck" published by the British Admiralty and the U. S. Hydrographic Bureau, as well as by the U. S. Coast and Geodetic Survey. These charts are included in this Index, and the localities referred to them of which there are no separate charts.

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# EXPLANATION OF THE PLATES.

## PLATE I.

Chart of the Bahamas, prepared by the Hydrographic Bureau, Commander C. D. Sigsbee, U. S. N., Hydrographer.

## PLATE II.

Fig. 1. Hogsty Reef, from a sketch sent by Captain W. J. Wharton, R. N., Hydrographer to the Admiralty. A few soundings made by the "Wild Duck" have been added outside the 100 fathom line.

Fig. 2. Longitudinal section across Hogsty Reef, from the 120 fathom point on the east to the 140 fathom line on the west.

Fig. 3. Transverse section from the 120 fathom line on the north to the 206 fathom point on the south.

Fig. 4. The same as Figure 2, on a larger scale, to show the slope of the lagoon from the eastern ledge to the main entrance of the lagoon.

Fig. 5. Section across the lagoon near the eastern ledge.

Fig. 6. Section across the lagoon to the west of South Cay somewhat to the east of the entrance.

Fig. 7. Section across the lagoon at its widest part, near the middle.

## PLATE III.

Charts of the vicinity of three prominent Blue Holes, from sketches kindly sent by Captain Wharton, R. N., Hydrographer to the Admiralty.

Fig. 1. Thirty-eight and seventeen fathom holes. These holes are south of the eastern extremity of Thunder Channel, Tongue of the Ocean.

Fig. 2. Thirteen fathom hole.

Fig. 3. Twenty-four fathom hole.

The holes in Figures 2 and 3 are immediately north of Blue Hole Point.

## PLATE IV.

Fig. 1. Section across the Straits of Florida, from Jupiter Inlet to Memory Rock, across the Little Bahama Bank to off Pensacola Cay.

Fig. 2. Section from Hillsboro Inlet across the Straits of Florida and the Northwest Providence Channel, to Mores Island and across the bank to off Great Abaco.

Fig. 3. Section from Fowey Rocks, across the Straits of Florida to Gun Cay, the Great Bahama Bank, the Northeast Providence Channel, to Royal Island and off Eleuthera.

Fig. 4. Section from Orange Cay across the Great Bahama Bank to Andros Island, the Tongue of the Ocean, Nassau, to off Eleuthera.

Fig. 5. Section across Salt Cay Bank, the Santaren Channel, the Hurricane Flats to Andros, the Tongue of the Ocean to Green Cay, to Harvey Cay across Exuma Sound to off Cat Island.

Fig. 6. Section across Salt Cay Bank, the Santaren Channel, the Hurricane Flats, the Tongue of the Ocean to Great Exuma, Exuma Sound, Conception Island, and off Watling's Island.

Fig. 7. Section from Cape Gracias a Dios across the Mosquito Bank to Rosalind Bank, Pedro Bank, and to Portland Bight, Jamaica.

## PLATE V.

Fig. 1 Section from Buenavista Bay (Cuba) across the Old Bahama Channel.

Fig. 2. Section from the Coast of Cuba across Romano and Paredon Cays and the Old Bahama Channel to Guinchos Cays.

Fig. 3. Section from the Coast of Cuba across Romano Cay and the Old Bahama Channel to a point somewhat west of Lobos Cay.

Fig. 4. Section from the Coast of Cuba to Romano Cay across the Old Bahama Channel to Diamond Point.

Fig. 5. Section from the Coast of Cuba to Cay Sabinal across the Old Bahama Channel to Blue Hole Point.

Fig 6 Section from Pan de Sama to off Cay San Domingo and to Ragged Island.

Fig. 7. From Point Azules (Cape Maysi) to Inagua.

Fig. 8 From Cape Isabella (Haiti) to Turk's Islands.

Fig. 9. From Cape Cabron (Haiti) to Navidad Bank.

Fig. 10. From Castle Island (Acklin Island) to Hogsty Reef to Inagua.

Fig. 11. From Cay Verde to South Cay (Mira por vos Bank) to Castle Island (Crooked Island Bank).

Fig. 12. From Cay Verde (Long Island) to Bird Rock (Crooked Island Bank).

Fig 13. From Cay Sal Bank across the Nicholas Channel to Bahia de Cadiz (Cuba).

Fig 14. Section from Coffin's Patches across the Straits of Florida to Elbow Cay (Cay Sal Bank).

Fig. 15. Section across Cay Sal Bank from Elbow Cay to Anguila.

Fig. 16 Section across the Straits of Florida from Key West (Sand Key) to Havana.

## PLATE VI.

Fig 1. Section off Alfred Sound (Inagua Island) to 222 fathoms.

Fig 2. Section off the southeast spit of Fortune Island (Crooked Island Bank) to 300 fathoms.

Fig. 3. Section off Exuma Harbor to 266 fathoms, west side of Exuma Sound.

Fig 4. Section off No Name Cay to 500 fathoms (south of Green Turtle Cay, Little Bahama Bank).

Fig 5. Section running northeast of Lagartos across the Yucatan Bank.

## PLATE VII.

Fig. 1. Section along the Virgin Island Bank from the eastern extremity of Porto Rico to off Anegada.

Fig. 2. North and south Section across the Virgin Bank through the Island of St. John.

Fig. 3. Section from the west side of Saba Bank to Saba and across the Anguilla-St. Bartholomew Bank.

Fig. 4. Section across Montserrat and Antigua.

Fig. 5. Section across Martinique.

Fig. 6. Section across Grenada.

Fig. 7. Section across the Grenadines Bank to off Barbados.

Fig. 8. Section from Aves Island across to Dominica.

Fig. 9. Section from Aves Ridge across St. Lucia to the Barbados Ridge.

## PLATE VIII.

Contour Chart of the Caribbean Sea, prepared by the Hydrographic Bureau in 1885, Commander J. R. Bartlett, U. S. N., Hydrographer for the "Three Cruises of the Blake."

## PLATE IX.

The Smaller Banks from Navidad to Watling Island, to illustrate the transition from such islands as Great Inagua, Watling Island, Rum Cay, Mariguana to Crooked Island and Caicos Banks, to such banks as Turk's Islands and Mira por vos Banks, and finally to the three easternmost sunken Banks of Mouchoir, Silver, and Navidad. From Hydrographic Chart No. 946, Admiralty Chart No. 393.

Fig. 1. Crooked Island Bank.

Fig. 2. Caicos Bank.

Fig. 3. Great and Little Inagua Islands.

Fig. 4. Mariguana Island.

Fig. 5. Turk's Islands Bank.

Fig 6. The northern part of the same bank, to show the mass of heads left to the south of Grand Turk Island by the disintegration of the former Grand Turk land. Reduced from Hydrographic Chart No. 1000.

Fig. 7. Mouchoir Bank.

Fig. 8. Silver Bank.

Fig. 9. Mira por vos Bank.

Fig. 10. Navidad Bank.

Fig. 11. Conception Island and Rum Cay.

Fig. 12. Watling Island.

## PLATE X.

From Hydrographic Charts Nos. $26^b$, $26^c$, 944, and 946.

Fig. 1. Little Bahama Bank. See Admiralty Chart No. 399, for a larger scale.

Fig. 2. The northern extremity of the eastern part of Great Bahama Bank, including New Providence to Eleuthera, and the Middle Ground to the southeast of New Providence.

Fig. 3. A part of the same Bank from New Providence as far as the Douglas Channel, on a larger scale than Fig. 2.

Fig. 4. The west face of Crooked Island Bank, from the southern spit of Fortune Island to Bird Rock, showing the disintegration of the lowlands of the banks, and the formation of lagoons and the line of soundings taken by the "Wild Duck" to 300 fathoms. Reduced from Admiralty Chart No. 393.

Fig. 5. The southwestern edge of Exuma Sound, showing the formation of the outer chains of cays from Great Exuma Island on the narrow shore plateau bounded by the 100 fathom line, and the disintegration of the inner face of Great and Little Exuma Islands to form the low cays, flats, shallows, and sand bores on the adjoining parts of the bank. The dotted line indicates the line of soundings taken by the "Wild Duck" to 266 fathoms. Reduced from Hydrographic Chart No. 26c.

Fig. 6. The southern extremity of Long Island, showing the transition of the western face of the central part of the island into the bank flats, and the breaking up of the west face of the southern promontory of Long Island by the Salina Flats. Reduced from Hydrographic Chart No. 26c.

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Fig. 3. The northeastern extremity of Andros with the Joulter Cays and Bores. Soundings in fathoms. Hydrographic Chart No. 1496.

Fig. 4. Washerwoman's Cut Channel (south of Andros), leading from the Tongue of the Ocean to Hurricane Hole. Soundings in fathoms. Hydrographic Chart No. 2077.

Fig. 5. The Ragged Islands Cays on the southeastern extremity of the Great Bahama Bank. Soundings in feet. Hydrographic Charts Nos. 341, 1399.

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## PLATE XII.

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Fig. 2. The Beminis, Gun Cay, and the adjoining flats to the eastward. Hydrographic Chart No. 1496.

Fig. 3. The three Bights dividing the Island of Andros to the south of Wide Opening. Hydrographic Chart No. 1496.

Fig 4. Great Stirrup Cay and the Sand Bores to the west of Great Harbor, on the northeastern point of the western shank of Great Bahama Bank. Hydrographic Chart No. 1432.

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## PLATE XIII.

Fig. 1. North Shore of Cuba from Port Padre to Cay Guajaba, showing the harbors of Nuevitas to Padre, and the mode of separation of the shore cays from the main island.

Fig. 2. The Cays of the North Shore of Cuba, from Cay Guajaba to Cay Coco.

Fig. 3. The Cays of the North Shore of Cuba from Buenavista Bay to Lanzanillo Cay, and the Boca de Cañete.

Fig. 4. The Western Cays of the North Shore of Cuba, from Boca de Cañete, Sagua la Grande to Cardenas Bay.

Fig. 5. The Cays of the Western Extremity of Cuba and the Colorado Reefs, from Inez de Soto Cay as far as Cape San Antonio. All figures from Hydrographic Chart No. 947.

## PLATE XIV.

Fig. 1. The Cays of the Coast off Sagua la Grande.

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Fig. 3. The Harbor of Baracoa, one of the most easterly indentations of the north shore of Cuba. Admiralty Chart No. 435.

Fig. 4. Alfred Sound, the reef harbor at the northwestern extremity of Great Inagua. Admiralty Chart No. 2022.

Fig. 5. Port Guantanamo, a flask-shaped harbor on the south shore of Cuba between Cape Maysi and Cape Cruz. Hydrographic Chart No. 377$^b$.

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## PLATE XV.

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## PLATE XVI.

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## PLATE XVII.

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## PLATE XIX.

Inland Vegetation. Pine Barren with Palmettos near Lake Cunningham, New Providence.

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## PLATE XXIII.

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## PLATE XXIV.

Part of North Shore of Great Isaac. On the northwest corner of the west shank of the Great Bahama Bank.

## PLATE XXV.

General View of a part of the South Shore of Great Isaac.

## PLATE XXVI.

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## PLATE XXVII.

A Stretch of the Western Coast of Eleuthera, between the Glass Window and Governor's Harbor.

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## PLATE XXIX.

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## PLATE XXXI.

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## PLATE XXXII.

Booby Island on the eastern edge of Douglas Channel, Great Bahama Bank.

## PLATE XXXIII.

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## PLATE XXXIV.

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## PLATE XXXV.

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## PLATE XXXVI.

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## PLATE XXXVII.

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A part of the West Shore of Fortune Island, south of the settlement (Crooked Island Bank).

## PLATE XXXIX.

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## PLATE XLII.

Yumuri Cañon, entrance to the Yumuri Valley, seen from the east shore of the harbor of Matanzas.

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A part of the Yumuri Valley.

## PLATE XLIV.

Elevated Reef (First Terrace) running along the north shore of Cuba between Matanzas and Havana, near the Canasi River. Cliffs composed of older limestones.

## PLATE XLV.

Entrance to Havana Harbor. Soboruco Reef in foreground.

## PLATE XLVI.

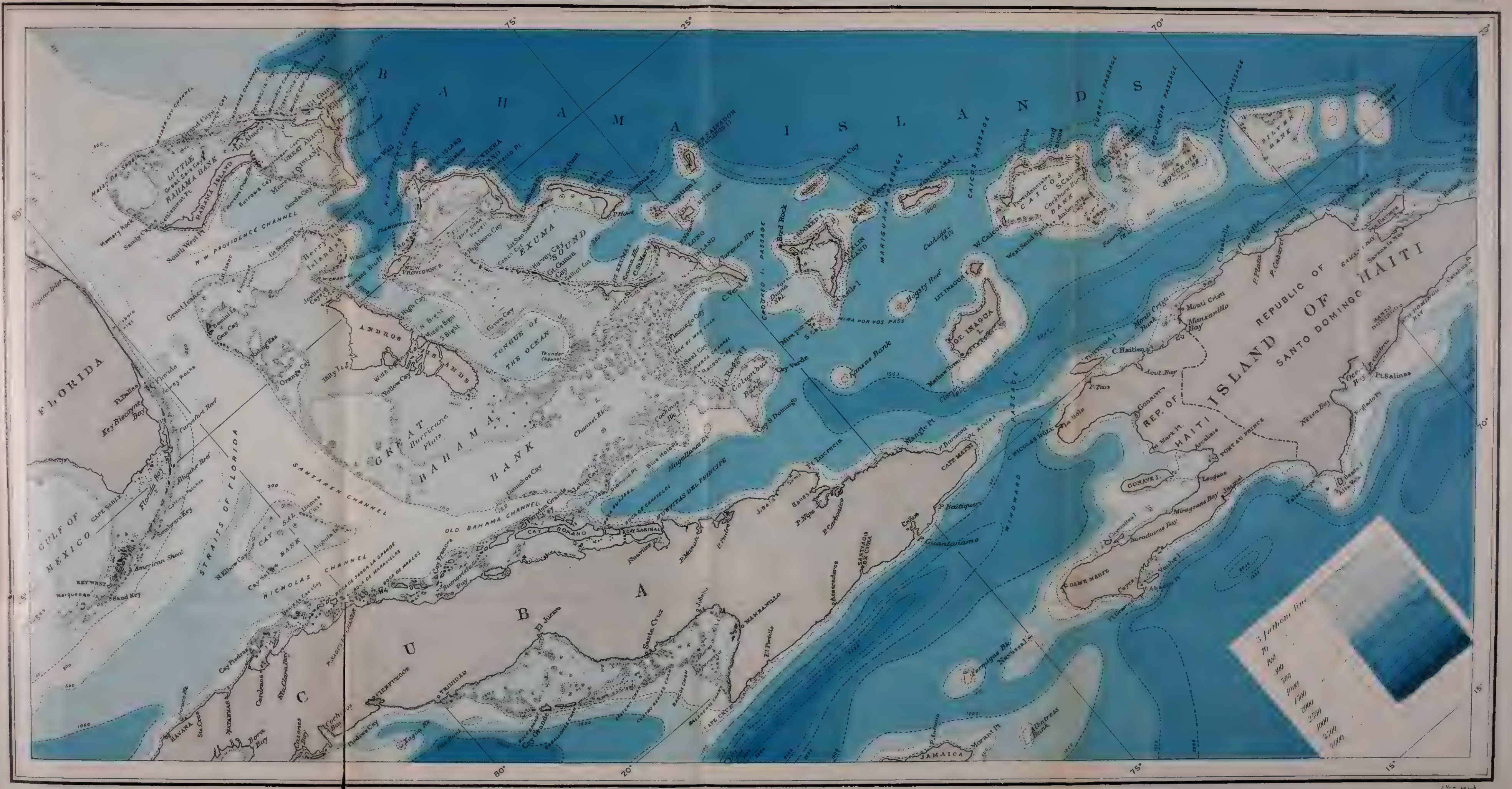
Patch of Soboruco near Morro Castle, Havana.

## PLATE XLVII.

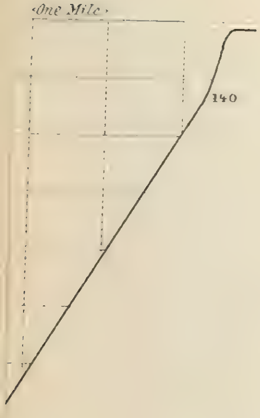
Morro Castle, entrance of Santiago de Cuba. Patch of Soboruco at right-hand corner.

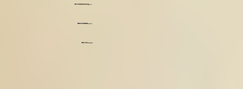
BAH
20°
NAVIDAD BANK
SALVADOR
LINGS I.)
4000
3500
3000
2500
2000
1500
1000
1000
500
CAY
Cabron
C. SAMANA
C. Rafael
Bird Rock
Cesa Bay
Sta. Barbara
Savana la Mar
ND
Clarence Hbr.
CROOKED I. PASSAGE
HAITI
C. Verd
Fort
Diana
Shl.
Catalina
100
500
1000
1500
SANTO DOMINGO
STO. DOMINGO BAY
CHANNEL
Cay
Caldera

# THE BAHAMAS



BAHAMA ISLANDS
LITTLE BAHAMA BANK
GREAT BAHAMA BANK
GREAT ABACO
GRAND BAHAMA ISLAND
N W PROVIDENCE CHANNEL
N E PROVIDENCE CHANNEL
NEW PROVIDENCE
ELEUTHERA ISLAND
EXUMA SOUND
TONGUE OF THE OCEAN
ANDROS ISLANDS
Berry Islands
Great Isaac
Bemini Is
Cat Cay
Orange Cay
Hurricane Flats
Columbus Bank
Cay Verde
Cay S.Domingo
LONG ISLAND
Conception I.
S. SALVADOR (WATLING'S I.)
Samana Cay
Rum Cay
CROOKED I.
ACKLIN ISLAND
Bird Rock
CROOKED I. PASSAGE
MARIGUANA PASSAGE
MARIGUANA I.
CAICOS PASSAGE
CAICOS
Providenciales
Grand Caicos
W. Caicos
S. Caicos
Cockburn Hbr
CAICOS BANK
Grand Turk
TURKS I. PASSAGE
MOUCHOIR PASSAGE
MOUCHOIR BANK
SILVER BANK PASSAGE
SILVER BANK
NAVIDAD BANK
Hogsty Reef
Kansas Bank
Mira por vos Pass
LIT. INAGUA
GT. INAGUA
Mathew Town
Castle I.
FLORIDA
Key Biscayne Bay
Ft. Dallas
Jupiter Inlet
Hillsboro Inlet
Fowey Rocks
Carysfort Reef
Alligator Reef
Florida Bay
CAPE SABLE
GULF OF MEXICO
KEY WEST
Marquesas Is.
Sand Key
American Shoal
Sombrero Key
STRAITS OF FLORIDA
CAY SAL BANK
SANTAREN CHANNEL
NICHOLAS CHANNEL
OLD BAHAMA CHANNEL
Cay Romano
Cay Sabinal
Cay Coco
Guajaba
BOCA DE CARAVELOS
Paredon Grande
Cay Francis
Cay Piedras
Magallenes Bk
Diamond Pt
Blue Hole Pt
Cochinos Bk
Channel Rk
Lobos Cay
Guinchos Cay
Mangle Pt
Pt. Lucrecia
CAPE MAYSI
P. Baitiquiri
Guantanamo
SANTIAGO DE CUBA
Bay of Manzanillo
El Jucaro
Santa Cruz
C. Cruz
CUBA
HAVANA
MATANZAS
Cardenas
Sta. Clara Bay
CIENFUEGOS
TRINIDAD
Cay Grande
Jagua Bk
WINDWARD PASSAGE
Navassa I.
Formigas Bk
Albatross Bank
Morant Pt
JAMAICA
TORTUGA I.
C. Haitien
Monte Cristi
Manzanillo Bay
Acul Bay
P. Paix
C. Nicolas Mole
GONAVE I.
Gonaives
St Mark Pt
Arcahaie
PORT AU PRINCE
Leogane
Miragoane Bay
Jacmel
Baradaires Bay
Cayemites I.
Cayes
Vache I.
DAME MARIE
Abacou Pt
REP. OF HAITI
REPUBLIC OF SANTO DOMINGO
ISLAND OF HAITI
SAMANA
SANTO DOMINGO
Neiva Bay
Ocoa Bay
Pt. Salinas
Beata I.
Alta Vela
Pt. Isabelle
Macoris Pt
C. Viejo Frances
Samana Bay
3 fathom line
10
100
300
500
1000
1500
2000
2500
3000
3500
4000
80°
75°
70°
25°
20°
15°


One Mile
140



40'

fathoms.

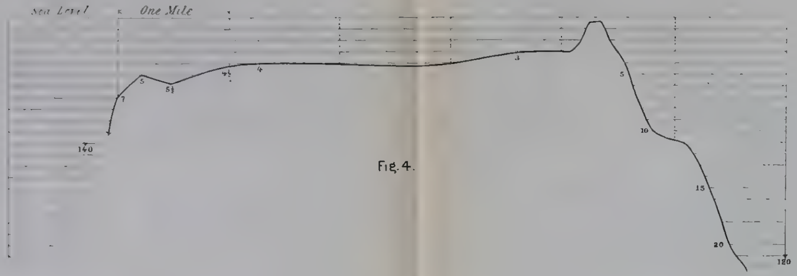


Fig. 4.

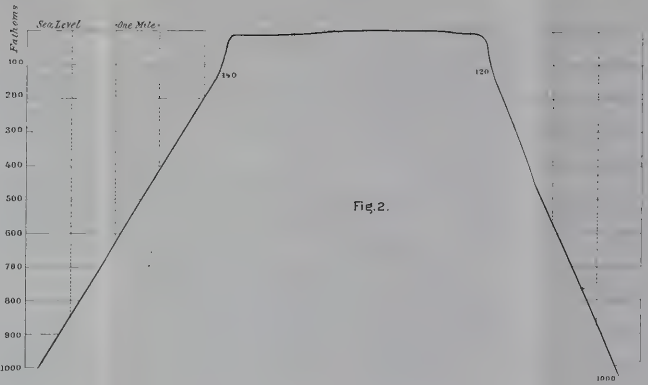


Fig. 2.

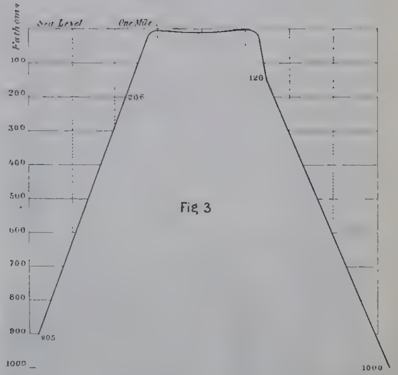


Fig 3

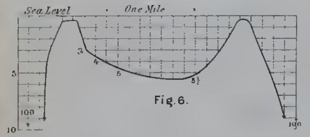


Fig. 6.

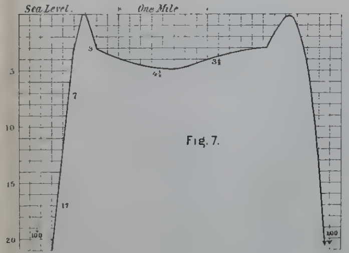


Fig. 7.

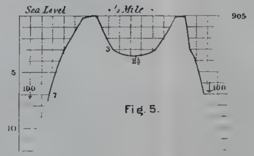


Fig. 5.

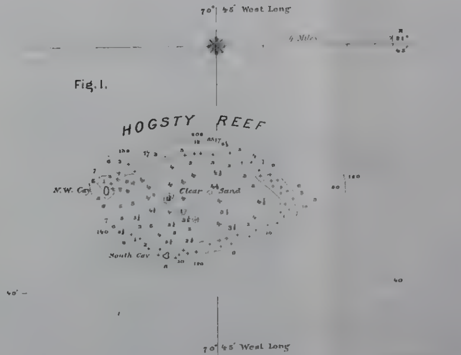
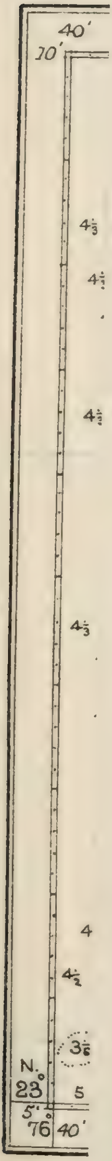

70° 45′ West Long
4 Miles
HOGSTY REEF
N.W. Cay
Clear Sand
South Cay
70° 45′ West Long

Fig. 1.

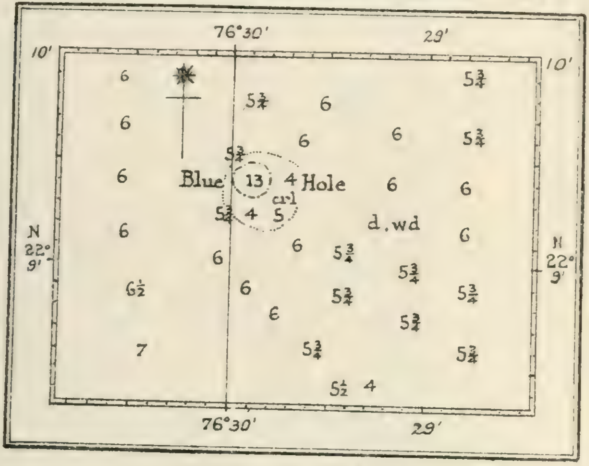
*Depths in fathoms.*

P. Meisel lith Boston


40'
10'
4⅓
4⅓
4⅓
4⅓
4
4½
3⅙
5
N.
23°
5'
76°
40'

2

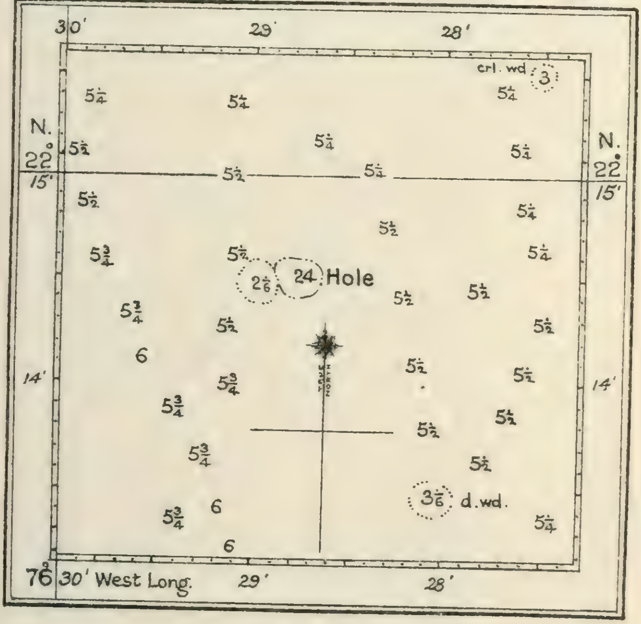
FROM A SURVEY BY COMM^R. EDWARD BARNETT 1844.


76°30'
29'
10'
10'
N
22°
9'
N
22°
9'
Blue Hole
13
crl
d.wd
76°30'
29'

*Soundings in Fathoms.*

3

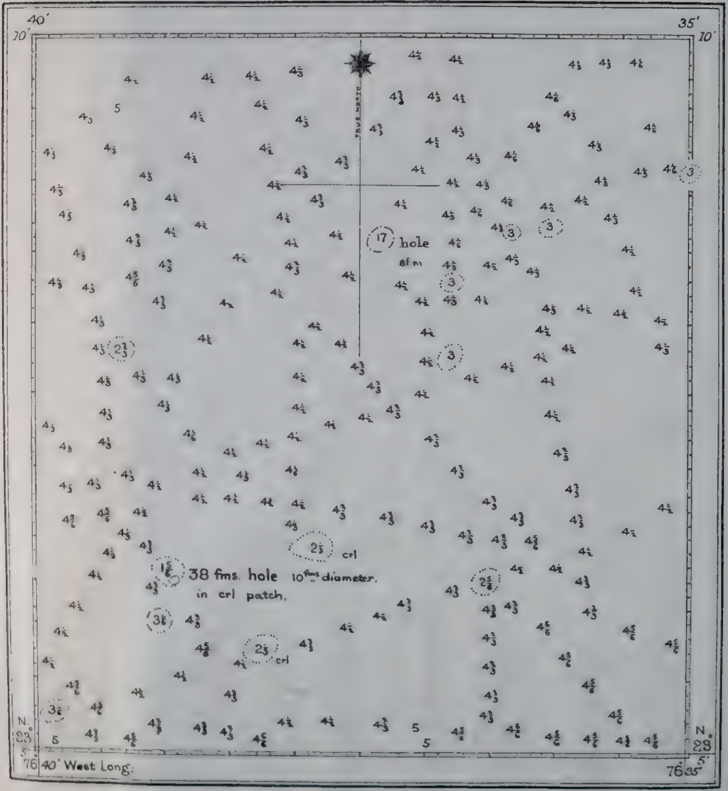
FROM A SURVEY BY COMM^R. EDWARD BARNETT 1844.


30'
29'
28'
crl. wd
3
N.
22°
15'
N.
22°
15'
14'
14'
24 Hole
2⅙
3⅙ d.wd.
76° 30' West Long.
29'
28'

*Soundings in Fathoms.*

1

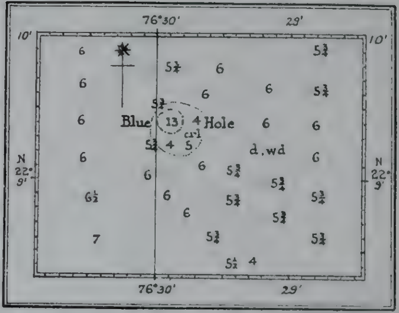
FROM A SURVEY BY LIEUT. G. B. LAWRANCE 1844.


40'
35'
10'
17 hole
8 fm
38 fms. hole 10 fms diameter.
in crl patch.
crl
N. 23° 5'
76 40' West Long.
76 35'

Soundings in Fathoms.

2

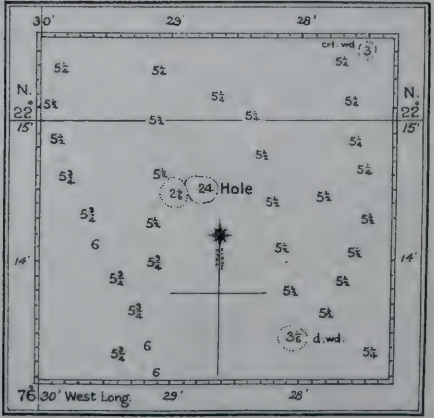
FROM A SURVEY BY COMMR. EDWARD BARNETT 1844.


76°30'
29'
10'
N 22° 9'
Blue 13 Hole
crl
d. wd

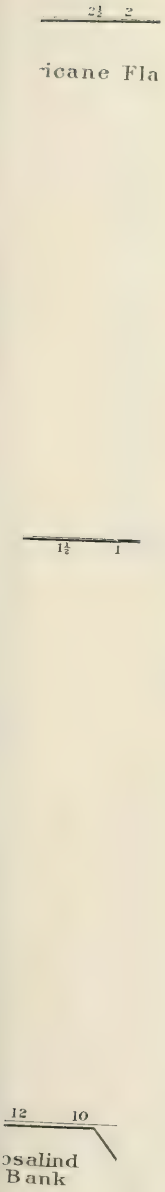
Soundings in Fathoms.

3

FROM A SURVEY BY COMMR. EDWARD BARNETT 1844.


30'
29'
28'
crl. wd
N. 22° 15'
14'
24 Hole
d. wd.
76 30' West Long.

Soundings in Fathoms.


2½ 2
icane Fla
1½ 1
12 10
osalind
Bank

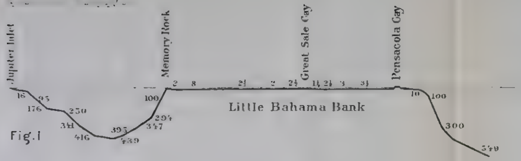


Fig. 1

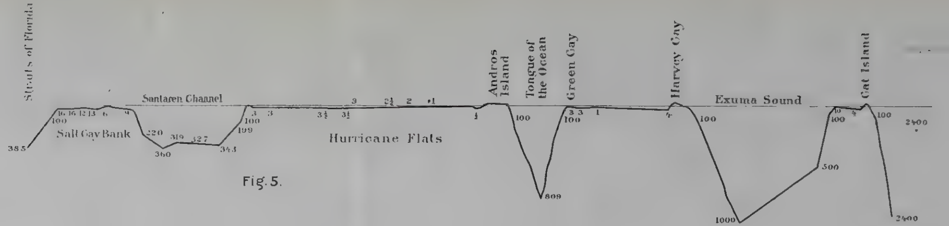


Fig. 5.

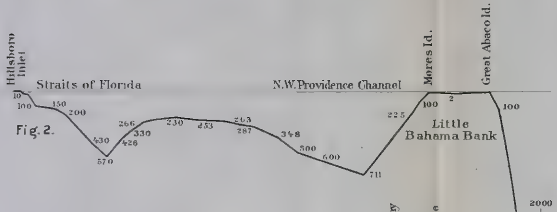


Fig. 2.

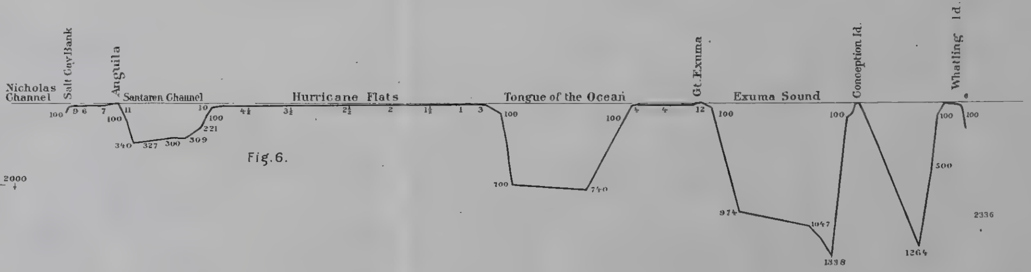


Fig. 6.

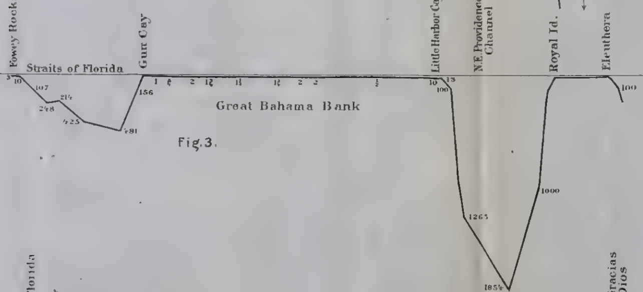


Fig. 3.

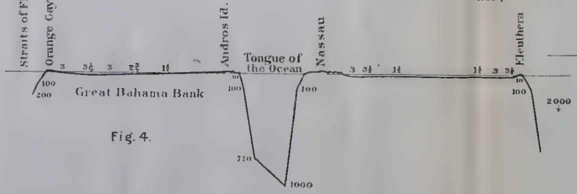


Fig. 4.

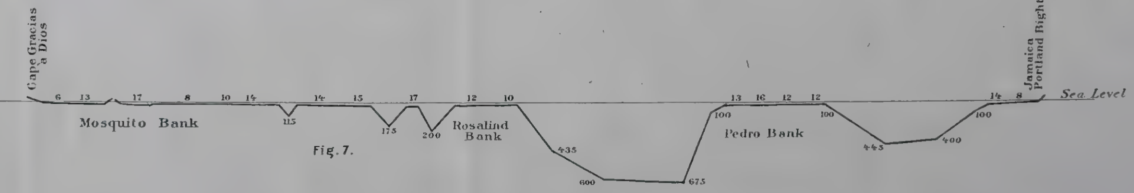
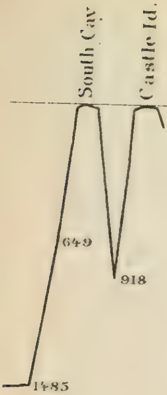


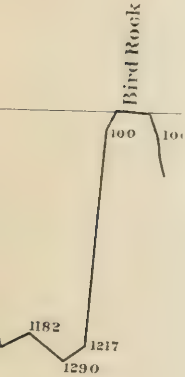
Fig. 7.

*Horizontal Scale, 1.25" = 60 nautical miles*
*Vertical Scale, 1" = 1000 fathoms*
*Depths in fathoms.*

B. Meisel lith. Boston


South Cav.
Castle Id.

Fi


Bird Rock

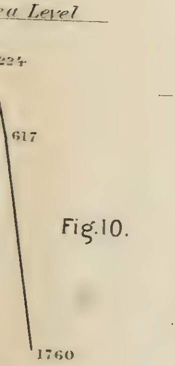

a Level
224
617
1760

Fig.10.

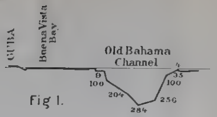


Fig 1.

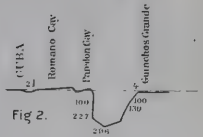


Fig 2.

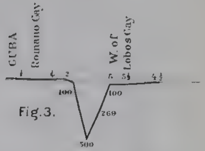


Fig. 3.

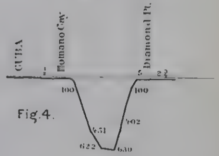


Fig. 4.

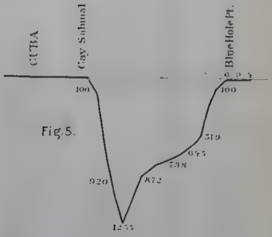


Fig. 5.

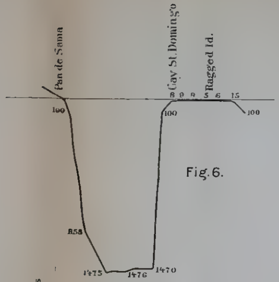


Fig. 6.

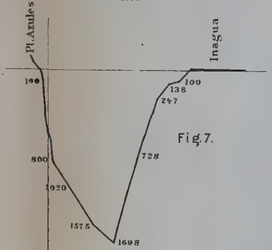


Fig. 7.

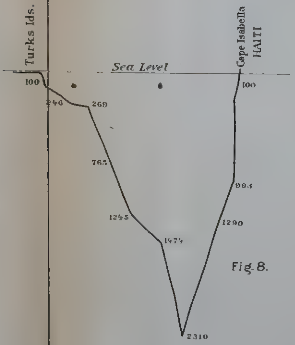


Fig. 8.

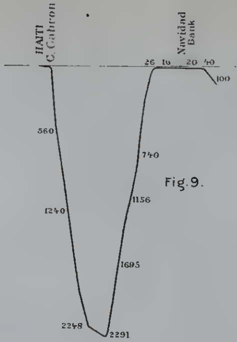


Fig. 9.

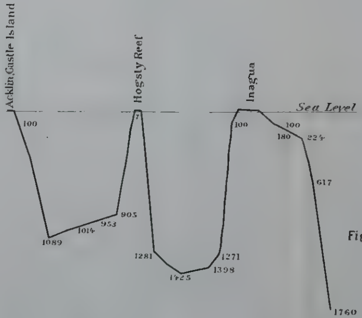


Fig. 10.

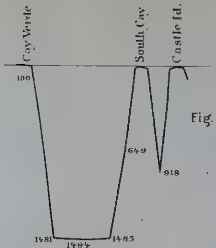


Fig. 11.

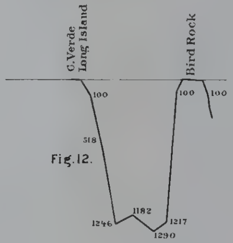


Fig. 12.

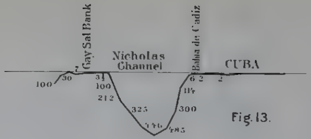


Fig. 13.

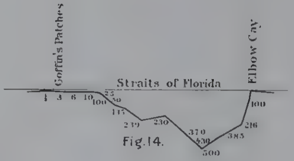


Fig. 14.

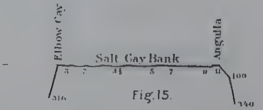


Fig. 15.

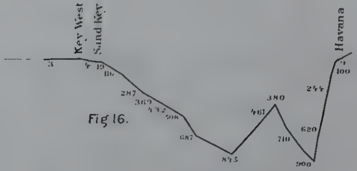


Fig 16.

*Horizontal Scale, 1.25" = 60 nautical miles*
*Vertical Scale, 1" = 1000 fathoms*
*Depths in fathoms.*

B Meisel lith Boston

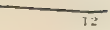
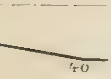


Fig.1



ne Mile =

ontal Sca
al Scale,
Depths

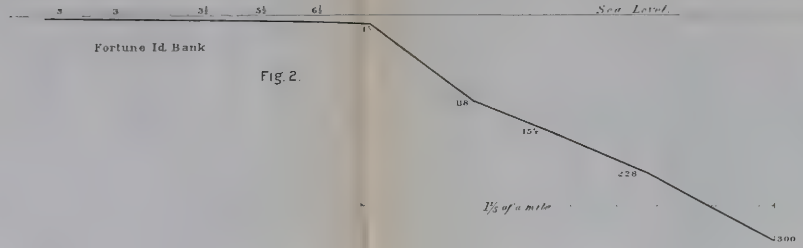


Fig. 2.

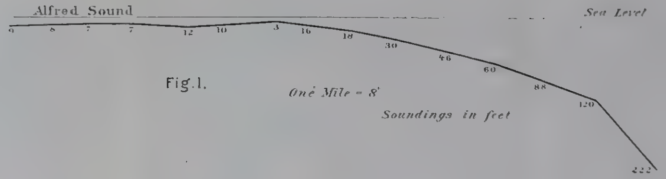


Fig. 1.

One Mile = 8″

Soundings in feet

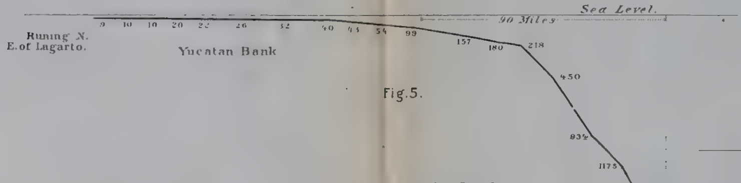


Fig. 5.

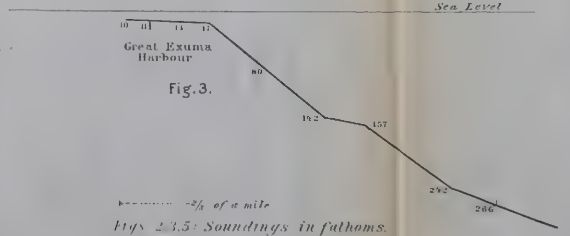
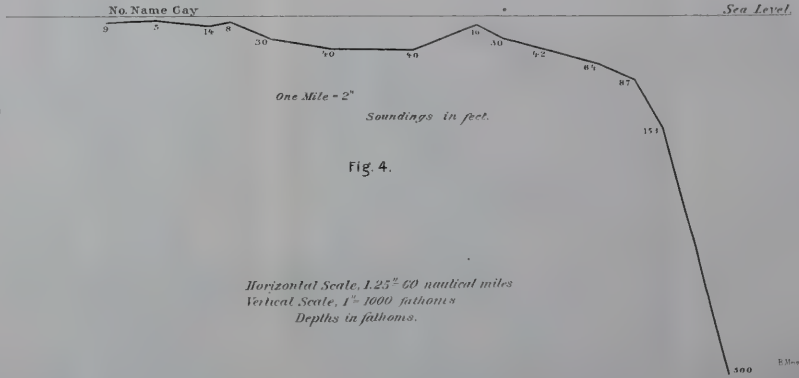


Fig. 3.

Figs 2.3.5: Soundings in fathoms.



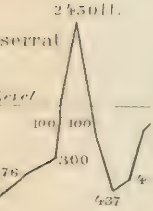
One Mile = 2″

Soundings in feet.

Fig. 4.

Horizontal Scale, 1.25″ = 60 nautical miles
Vertical Scale, 1″ = 1000 fathoms
Depths in fathoms.

B. Meisel lith Boston


2450ft.
serrat
evel
100
100
300
76
437
4

Fi

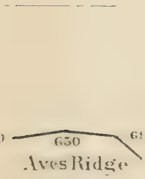

630
6
Aves Ridge

PLATE V.

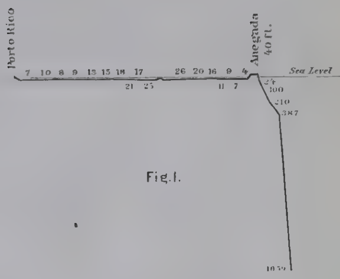


Fig. 1.

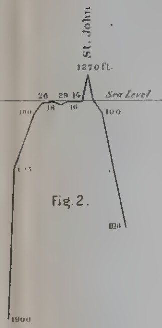


Fig. 2.

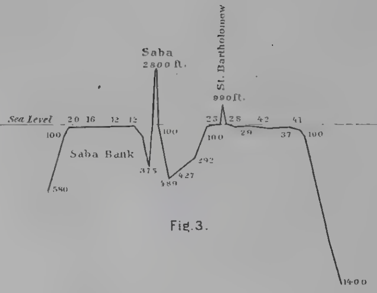


Fig. 3.

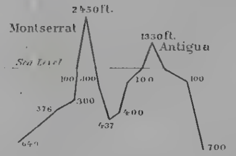


Fig. 4.

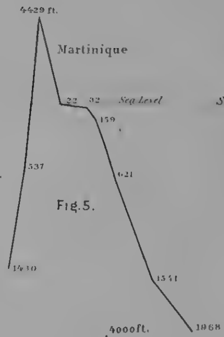


Fig. 5.

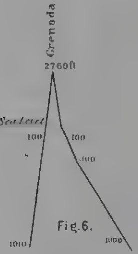


Fig. 6.

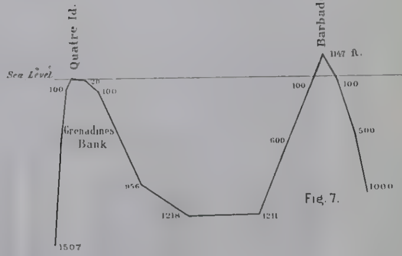


Fig. 7.

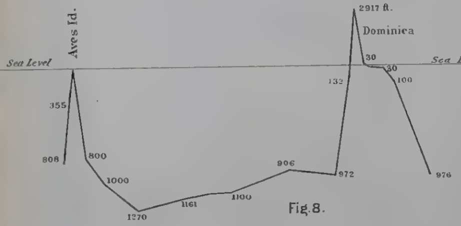


Fig. 8.

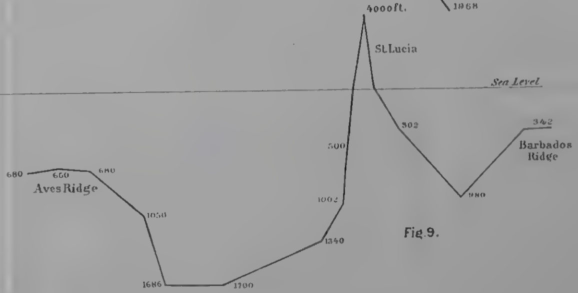
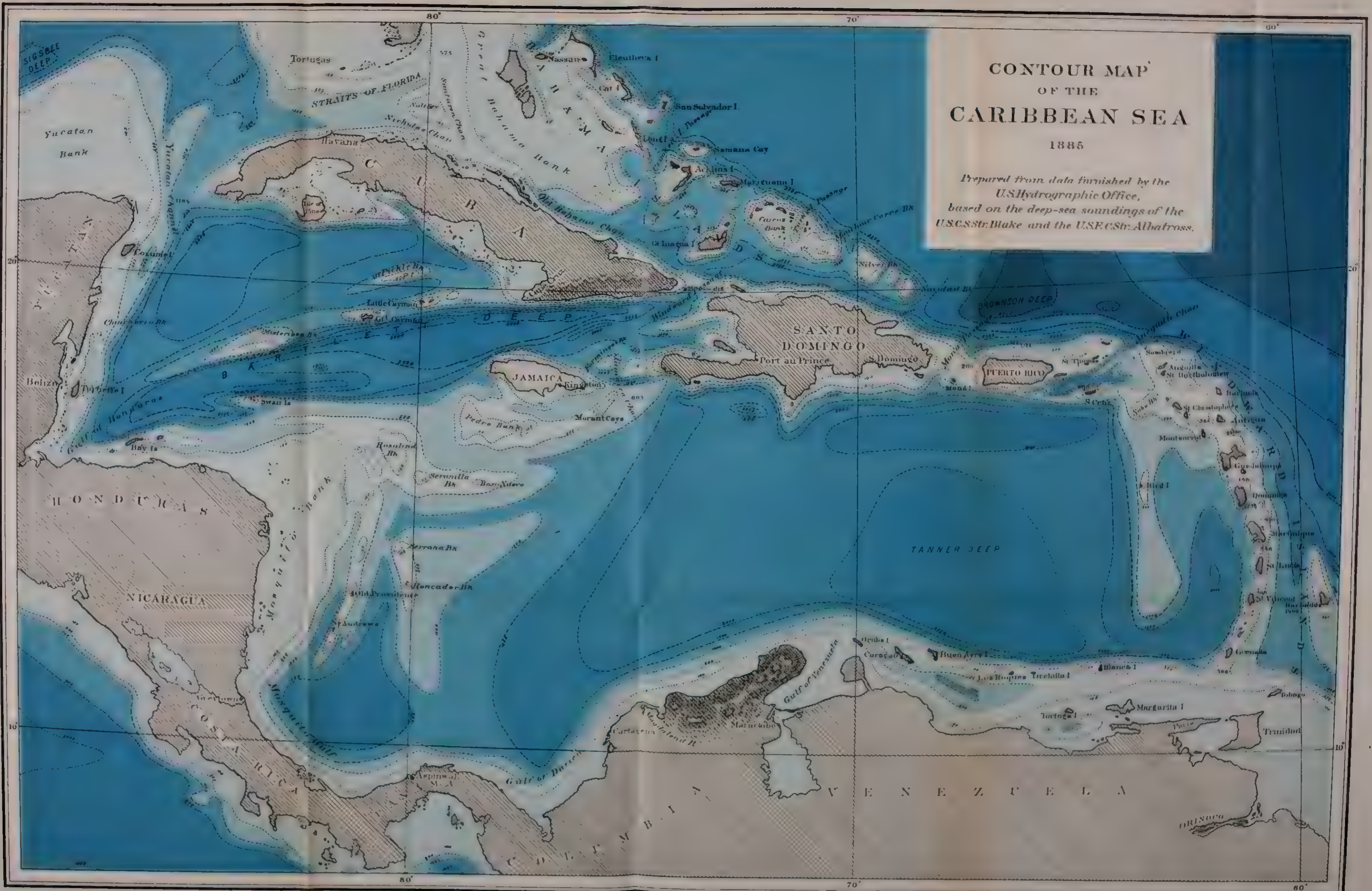


Fig. 9.

*Horizontal Scale, 1.25"= 60 nautical miles*
*Vertical Scale, 1"= 1000 fathoms*
*Depths in fathoms.*

B Meisel lith Boston

60°
ra I
San
Long I.d
Crooked I.
Po
S
L
1000
1000
100



CONTOUR MAP
OF THE
CARIBBEAN SEA
1885

*Prepared from data furnished by the U.S. Hydrographic Office, based on the deep-sea soundings of the U.S.C.S.Str. Blake and the U.S.F.C.Str. Albatross.*

80°
70°
60°
20°
10°
SIGSBEE DEEP
Tortugas
STRAITS OF FLORIDA
Yucatan Bank
Yucatan Chan
Great Bahama Bank
BAHAMA ISLANDS
Nassau
Eleuthera I
Cat I
San Salvador I.
Samana Cay
Acklins I
Mariguana I
Caicos Bank
Mouchoir Carre Bk
Silver Bk
Navidad Bk
Gt Inagua I
Havana
CUBA
Isle of Pines
Old Bahama Chan
Nicholas Chan
Cozumel
YUCATAN
Chinchorro Bk
Pickle Bk
Little Cayman
Gt Cayman
BARTLETT DEEP
Windward Passage
Belize
Turneffe I
Swan Is
Gulf of Honduras
Bay Is
JAMAICA
Kingston
Morant Cays
Pedro Bank
Rosalind Bk
Serranilla Bk
Baxo Nuevo
Mosquito Bank
Serrana Bk
Roncador Bk
Old Providence
St Andrews
HONDURAS
NICARAGUA
COSTA RICA
Mosquito Gulf
Aspinwall
Gulf of Darien
SANTO DOMINGO
Port au Prince
S. Domingo
Mona Passage
Mona I
PUERTO RICO
St Thomas
S. Cruz
BROWNSON DEEP
Anegada Chan
Sombrero
Anguilla
St Bartholomew
Barbuda
Saba Bk
St Christopher
Antigua
Montserrat
Guadeloupe
Bird I
Dominica
Martinique
St Lucia
St Vincent
Barbados
Grenada
Tobago
Trinidad
WINDWARD ISLANDS
TANNER DEEP
Oruba I
Curaçao
Buen Ayre I
Los Roques
Orchilla I
Blanca I
Tortuga I
Margarita I
Gulf of Venezuela
Maracaibo
Cartagena
Magdalena R.
COLOMBIA
VENEZUELA
ORINOCO

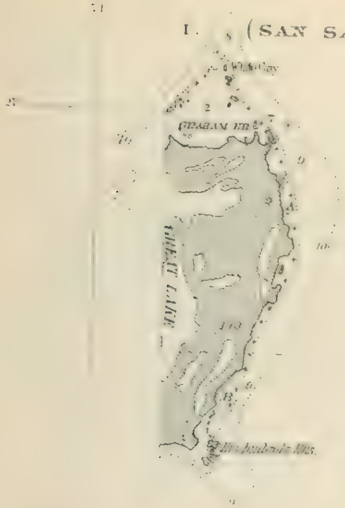

(SAN SALVADOR)
GRAHAM HR.
GREAT LAKE
9
10
2
7

Fig. 12

Fig. 6

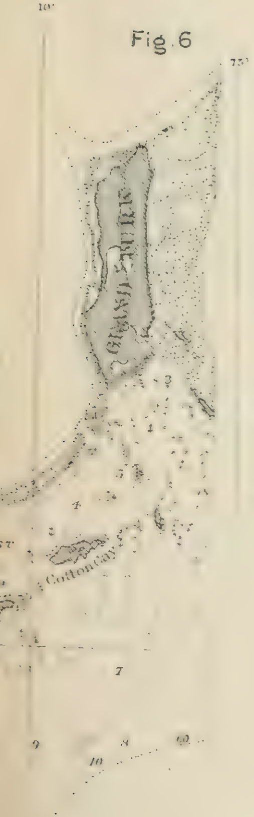
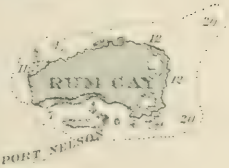

GRAND CAICOS
Cotton Cay
73°
3
4
5
7
9
10

Fig. 11


RUM CAY
PORT NELSON
12
20
6

E Me[illegible] th Bos

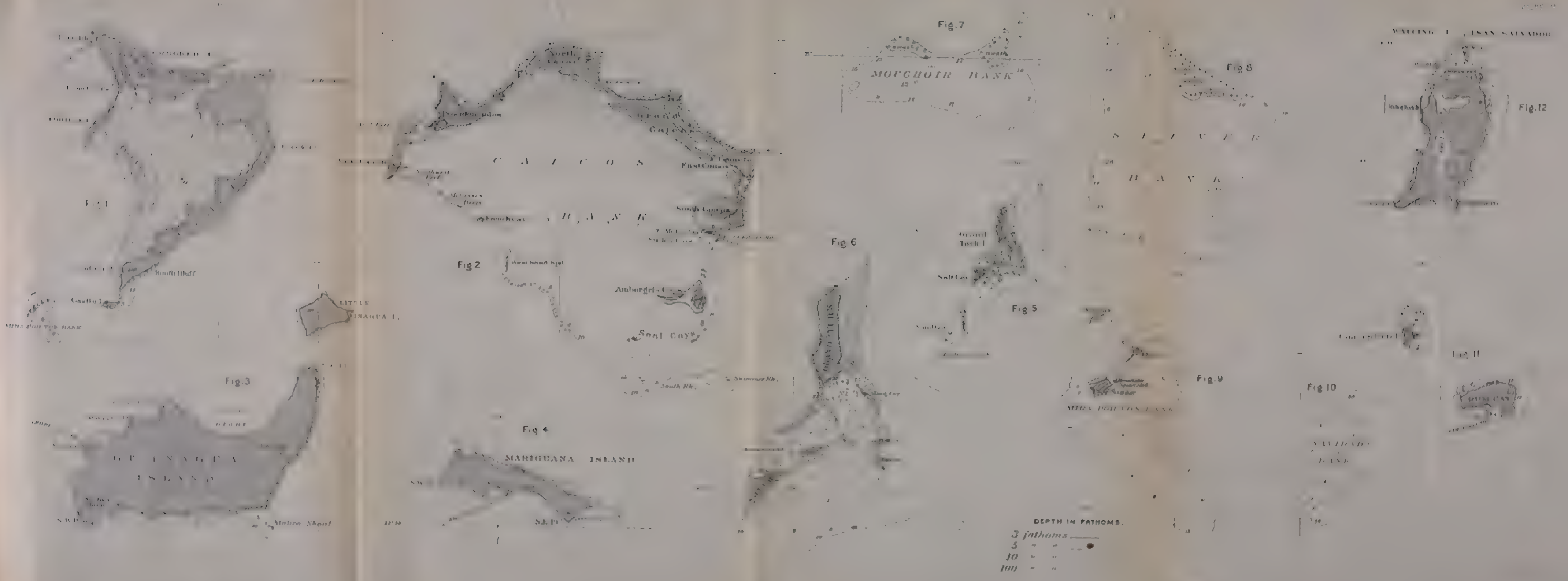


Fig. 1
South Bluff
LITTLE INAGUA I.
MIRA POR VOS BANK
Fig. 2
West Sand Spit
Ambergris Cay
Seal Cays
South Rk.
Swimmer Rk.
North Caicos
Grand Cay
East Caicos
South Caicos
CAICOS BANK
Fig. 3
GT. INAGUA ISLAND
Fig. 4
MARIGUANA ISLAND
S.E. Pt.
Fig. 5
Grand Turk I.
Salt Cay
Fig. 6
GRAND TURK
Fig. 7
MOUCHOIR BANK
Fig. 8
SILVER BANK
Fig. 9
MIRA POR VOS BANK
Fig. 10
NAVIDAD BANK
Fig. 11
Fig. 12
WATLING I. (SAN SALVADOR)
Conception I.
DEPTH IN FATHOMS.
3 fathoms
5 " "
10 " "
100 " "

ay
Eleuthera Pt.
FORTUNE ISL.
(or Long Cay)
North Cay
12
154
300
7
Wide Opening
Stocking I.
I.
75
10
10
Lit. Exuma I.
2½
1
½
C. VERD
2

B Meisel, lith. Boston

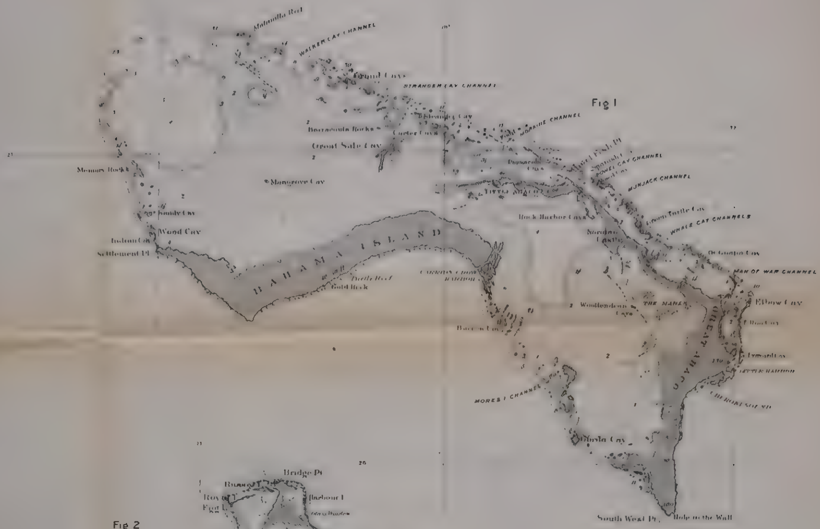
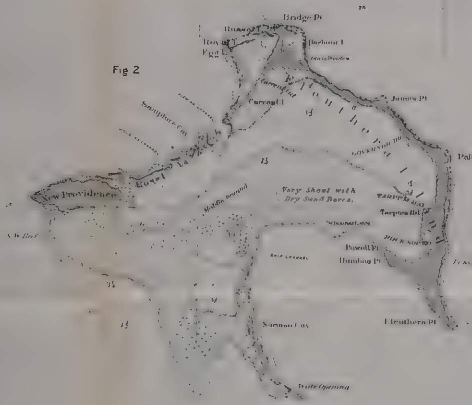

Matanilla Reef
WALKER CAY CHANNEL
Grand Cays
STRANGER CAY CHANNEL
Barracouta Rocks
Carter Cays
Great Sale Cay
Mangrove Cay
Memory Rock
Sandy Cay
Wood Cay
Indian Cay
Settlement Pt
BAHAMA ISLAND
Gold Rock
MORAINE CHANNEL
Little Abaco
Rock Harbor Cays
MUNJACK CHANNEL
Green Turtle Cay
WHALE CAY CHANNEL
Norman Castle
MAN OF WAR CHANNEL
Elbow Cay
Woodendean Cays
THE NARES
GREAT ABACO
Lynyard Cay
LITTLE HARBOUR
CHEROKEE SOUND
Burrow Cay
MORES I. CHANNEL
Gorda Cay
South West Pt.
Hole in the Wall

Fig 1

Fig 2


Bridge Pt
Harbour I
Royal I
Egg I
Current Cut
Current I
James Pt
Samphire Cay
Royal Island
New Providence
ELEUTHERA
Palmetto Pt
Very Shoal with Dry Sand Bores.
Tarpum Bay
Powell Pt
Bamboo Pt
ROCK SOUND
Norman Cay
Eleuthera Pt

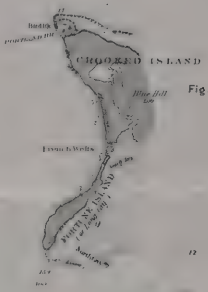
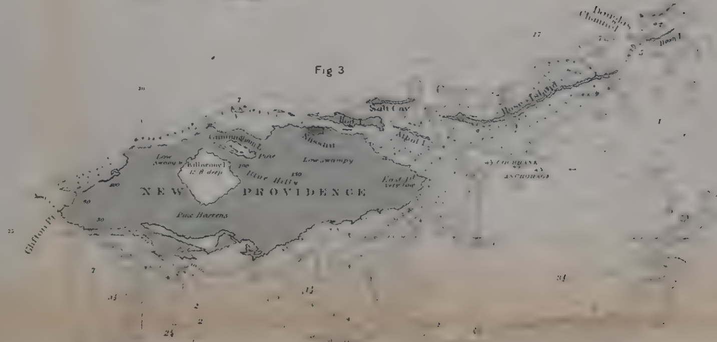

Bird Rk
CROOKED ISLAND
Blue Hill
French Wells
FORTUNE ISLAND (or Long Cay)
12

Fig.4

Fig 3


Douglas Channel
Rose Island
Salt Cay
Hog I
Athol I
Nassau
Low swampy
Killarney L
Blue Hills
NEW PROVIDENCE
East Pt
Pine Barrens
Clifton Pt
ANCHORAGE

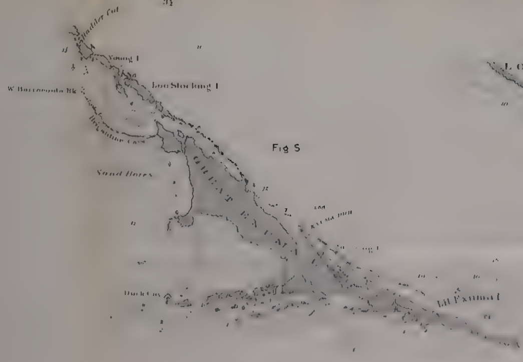

Young I
Loo Stocking I
W Barracouta Rk
Sand Bores
GREAT EXUMA
Lit Exuma
Duck Cay

Fig 5

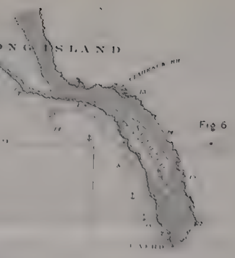

LONG ISLAND

Fig 6

achan Cay

93
190
10
26
WEST

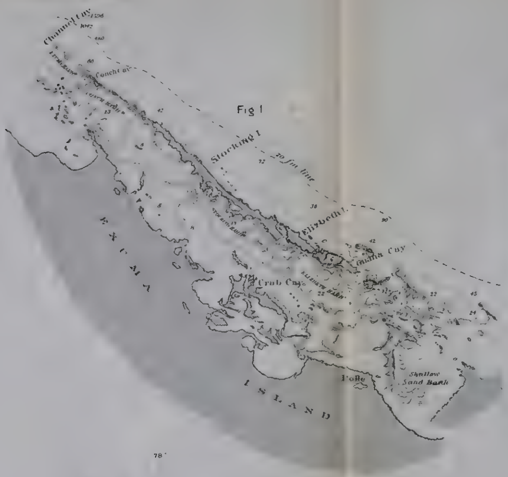

Channel Cay
Conch Cay
Stocking I.
20 fm line
Elizabeth I.
Guana Cay
Crab Cay
EXUMA ISLAND
Potte
Shallow Sand Bank

Fig 1

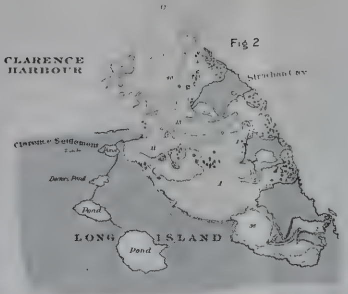

CLARENCE HARBOUR
Strachan Cay
Clarence Settlement
Pond
Doctors Pond
Pond
LONG ISLAND
Pond

Fig 2

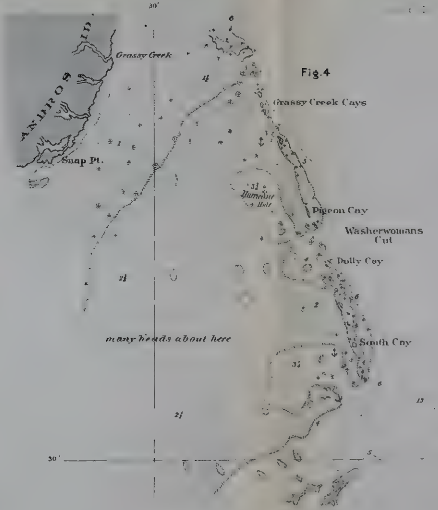

30'
ANDROS ID.
Grassy Creek
Snap Pt.
Grassy Creek Cays
Pigeon Cay
Washerwomans Cut
Dolly Cay
South Cay
many heads about here
30'

Fig. 4

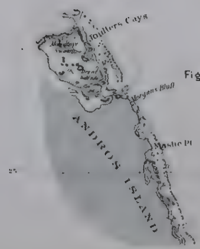

Joulters Cays
Morgans Bluff
ANDROS ISLAND

Fig. 3

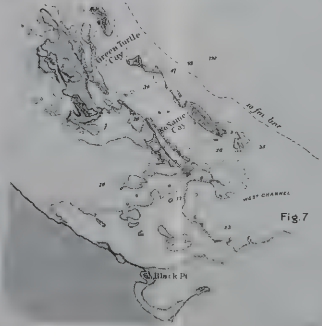

Green Turtle Cay
No Name Cay
10 fm line
WEST CHANNEL
Black Pt

Fig. 7

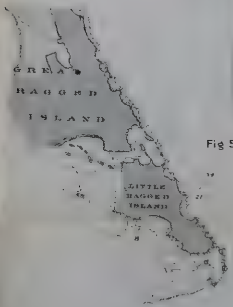

GREAT RAGGED ISLAND
LITTLE RAGGED ISLAND

Fig 5

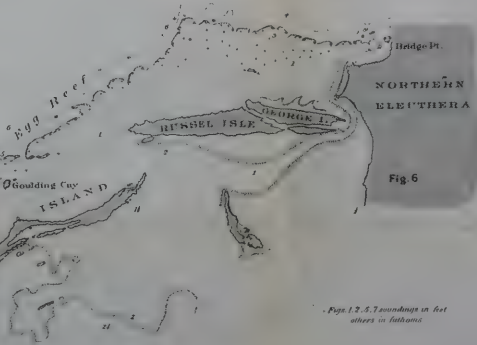

Bridge Pt.
NORTHERN ELEUTHERA
Egg Reef
RUSSEL ISLE
GEORGE I.
Goulding Cay
ROYAL ISLAND
Egg Id.

Fig. 6

Figs. 1. 2. 5. 7 soundings in feet
others in fathoms

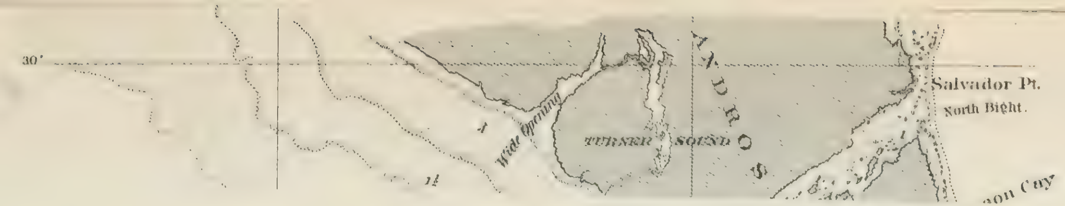

30'
1½
1
Wide Opening
TURNER SOUND
ANDROS
Salvador Pt.
North Bight.
on Cay

Fig. 3

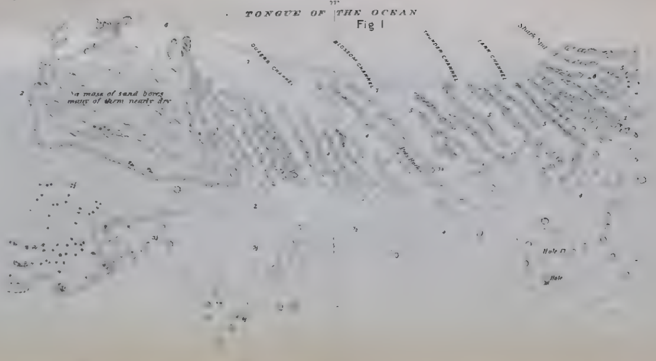

77°
TONGUE OF THE OCEAN
QUEEN CHANNEL
BLOSSOM CHANNEL
THUNDER CHANNEL
LARK CHANNEL
Shark Spit
a mass of sand bores many of them nearly dry
Hole
Hole

Fig 1

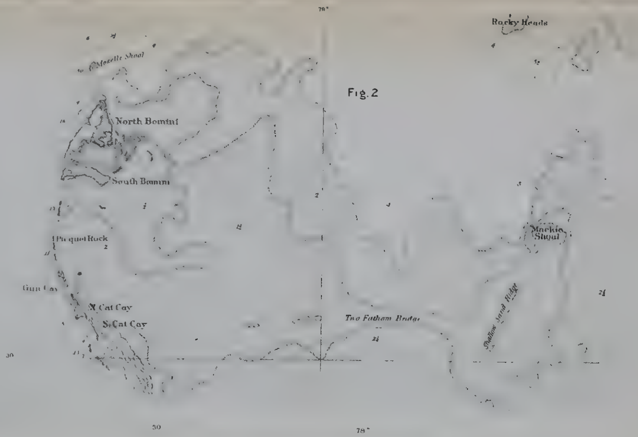

79°
Rocky Heads
Moselle Shoal
North Bimini
South Bimini
Piquet Rock
Gun Cay
N. Cat Cay
S. Cat Cay
Mackie Shoal
Shallow Sand Ridge
Two Fathom Bridge
30
78°

Fig. 2

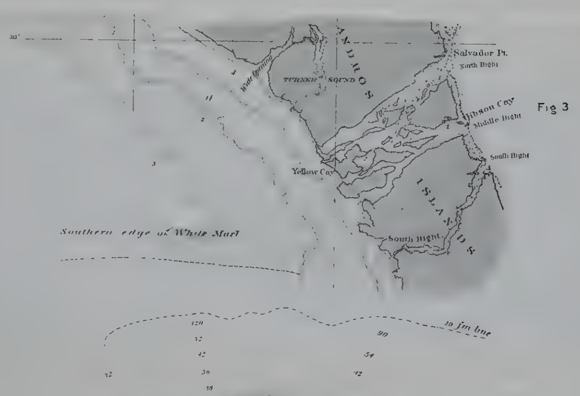

30'
ANDROS
ISLANDS
TURNER SOUND
Wide Opening
Salvador Pt.
North Bight
Gibson Cay
Middle Bight
South Bight
Yellow Cay
South Bight
Southern edge of White Marl
10 fm line

Fig 3

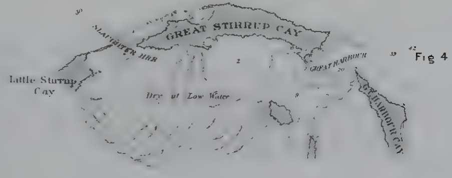

GREAT STIRRUP CAY
SLAUGHTER HBR
GREAT HARBOUR
GT. HARBOUR CAY
Little Stirrup Cay
Dry at Low Water

Fig 4

Soundings of fig. 4 in feet
others in fathoms

[illegible] Boston

Fig 1

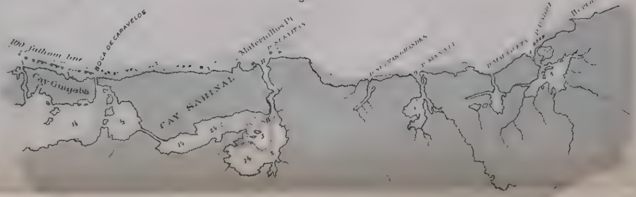

100 fathom line
BOCA DE CARAVELOS
Cay Guajaba
CAY SABINAL
Maternillos Pt
Hermanos Pt

Fig 2

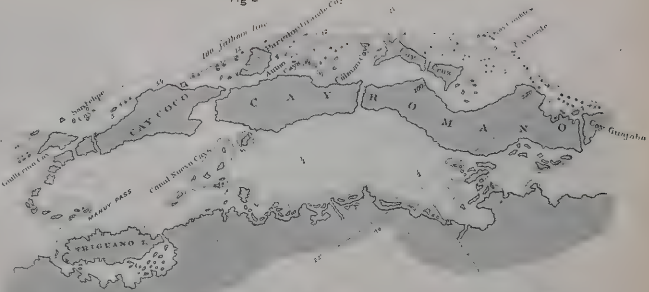

100 fathom line
Paredon Grande Cay
Antom Cays
Caiman Cay
Cay Cruz
Cay Verde
Sanfelipe
CAY COCO
C A Y R O M A N O
Cay Guajaba
Guillermo Cay
Canal Nuevo Cays
MANUY PASS
TRIGUANO I.

Fig 3

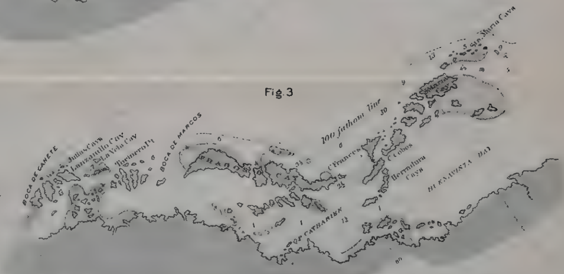

Sta Maria Cays
100 fathom line
BOCA DE CANETE
Julias Cays
Lanzanillo Cay
La Vela Cay
Toruero Pt
BOCA DE MARCOS
FRAGOS CAY
C Frances
C Cobos
Herradura Cays
BUENAVISTA BAY
P OF CATBARIEN

Fig 4

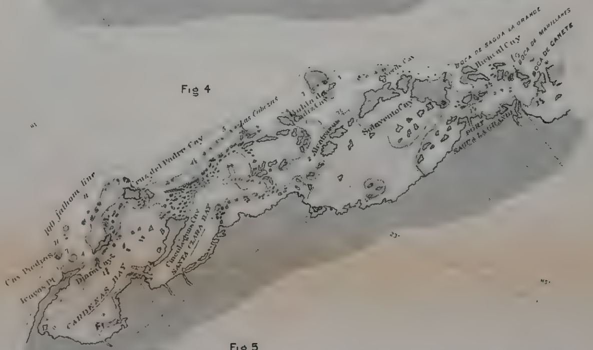

BOCA DE SAGUA LA GRANDE
Bencal Cay
BOCA DE MARILLANES
BOCA DE CANETE
Verde Cay
Las Cabezas
Cruz del Padre Cay
Bahia de Cadiz Cay
Alcatraces
Solaveno Cay
PORT SAGUA LA GRANDE
100 fathom line
Cay Piedras
Icacos Pt
Diana Cays
CARDENAS BAY
Cinco Leguas Cay
SANTA CLARA BAY

Fig 5

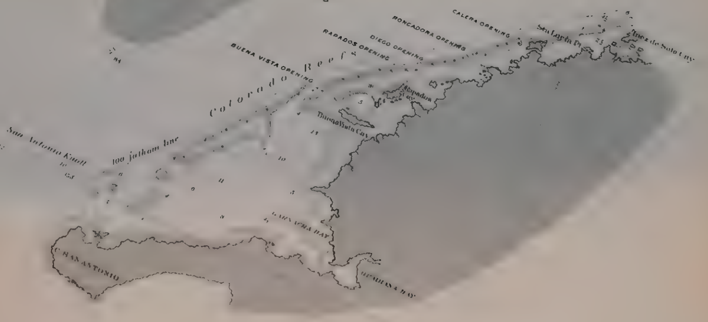

CALERA OPENING
RONCADORA OPENING
DIEGO OPENING
RAPADOS OPENING
BUENA VISTA OPENING
Colorado Reefs
Sta Lucia Pt
Inez de Soto Cay
Rapados Cay
Buena Vista Cay
San Antonio Knoll
100 fathom line
C SAN ANTONIO

Fig. 6

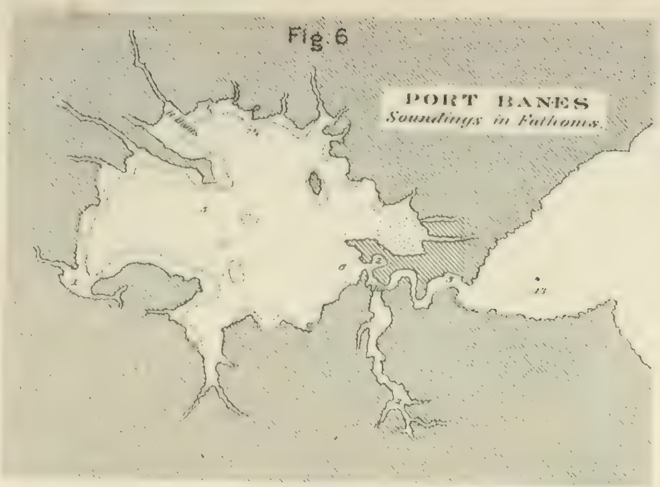
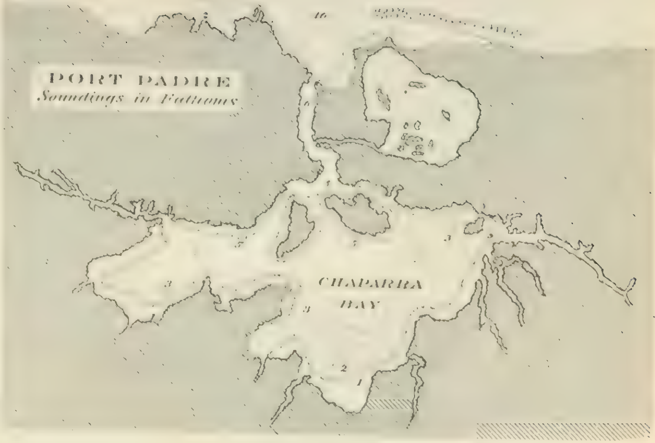

PORT BANES
Soundings in Fathoms.
R. Banes
3
1
6
2
3
13
2

Fig. 7


PORT PADRE
Soundings in Fathoms.
CHAPARRA
BAY
16
6
1
5
3
3
3
2
1

B. Meisel lith. Boston

Fig. 1

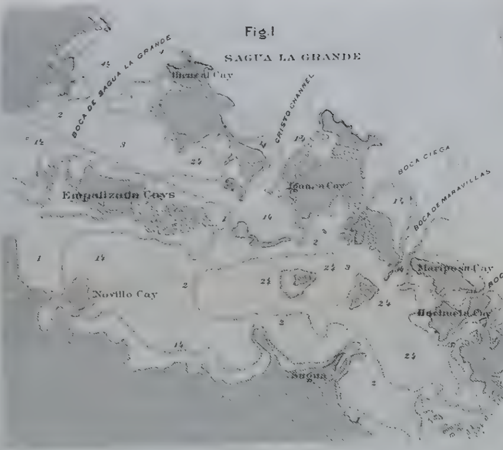

SAGUA LA GRANDE
BOCA DE SAGUA LA GRANDE
Bruzal Cay
CRISTO CHANNEL
Empalizada Cays
Iguana Cay
BOCA CIEGA
BOCA DE MARAVILLAS
Mariposa Cay
BOCA DE CANETE
Hacinela Cay
Novillo Cay
Sagua

Fig. 2

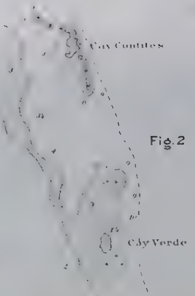

Cay Cuntiles
C. Jy Verde

Fig. 3

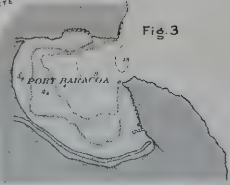

PORT BARACOA

Fig. 4

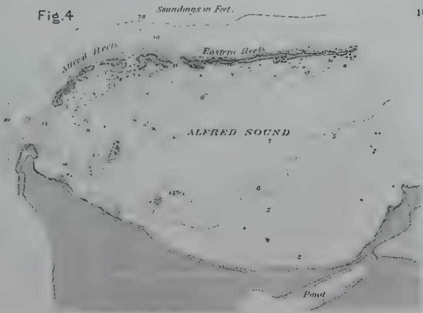

Soundings in Feet.
Alfred Reefs
Eastern Reefs
ALFRED SOUND
Pond

Fig. 5

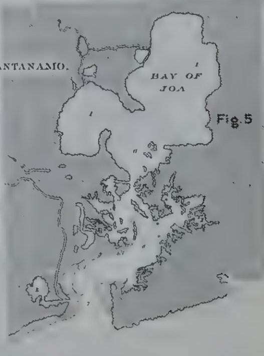

PORT GUANTANAMO.
BAY OF JOA

Fig. 6

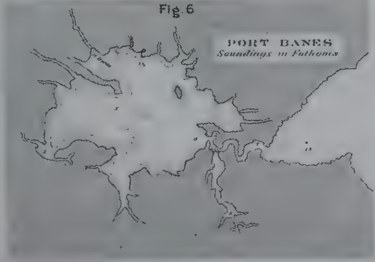
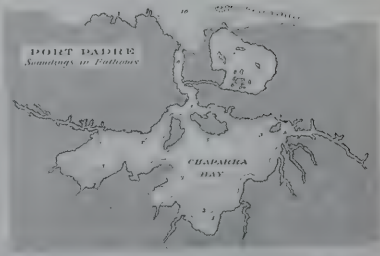
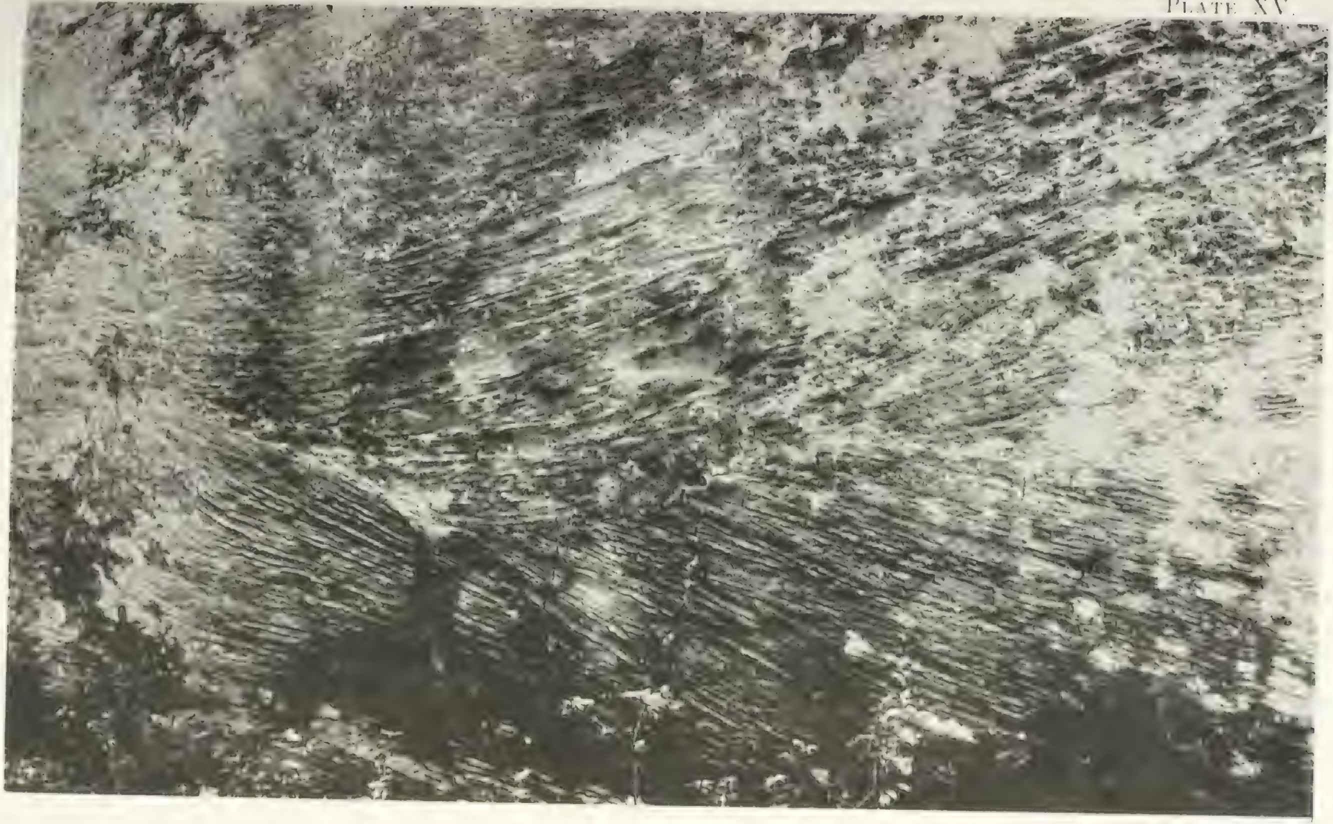

PORT BANES
Soundings in Fathoms

Fig. 7


PORT PADRE
Soundings in Fathoms
CHAPARRA BAY

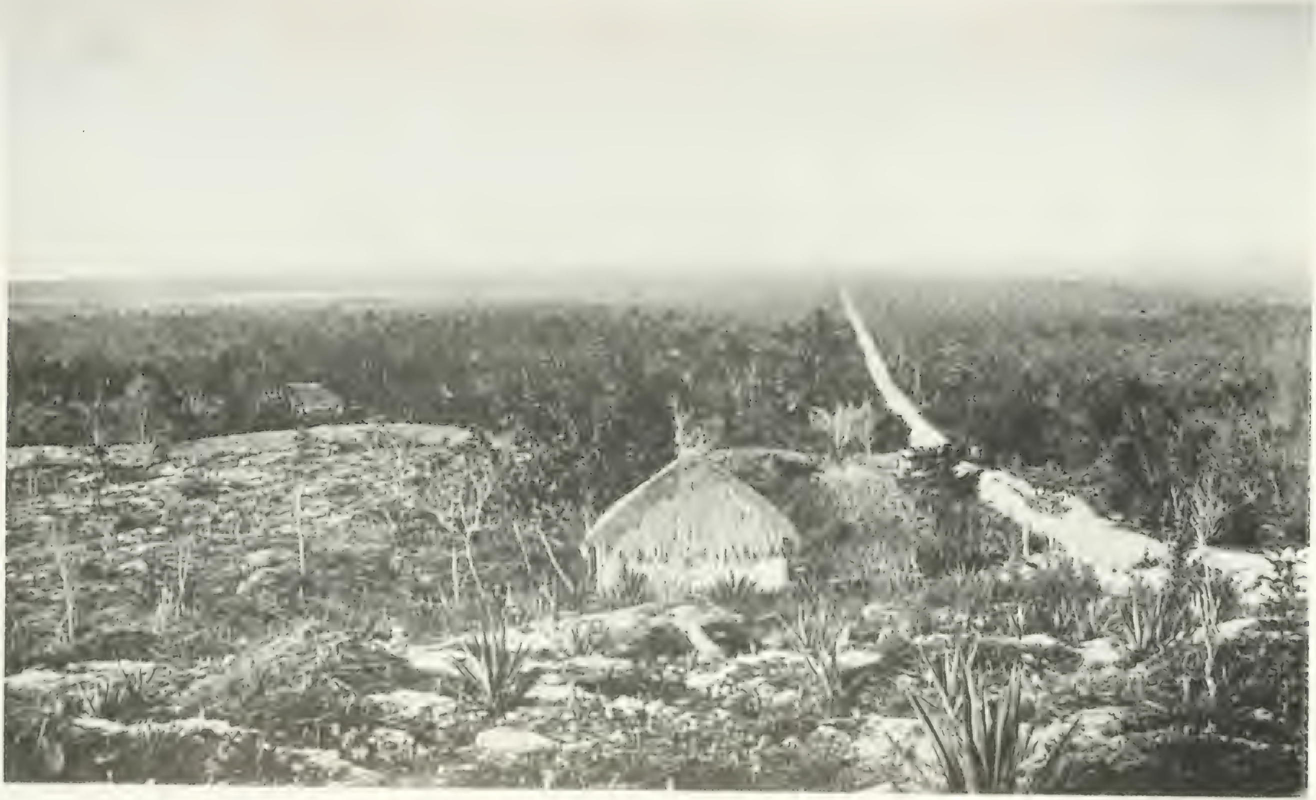
[illegible] Boston

PLATE XV.



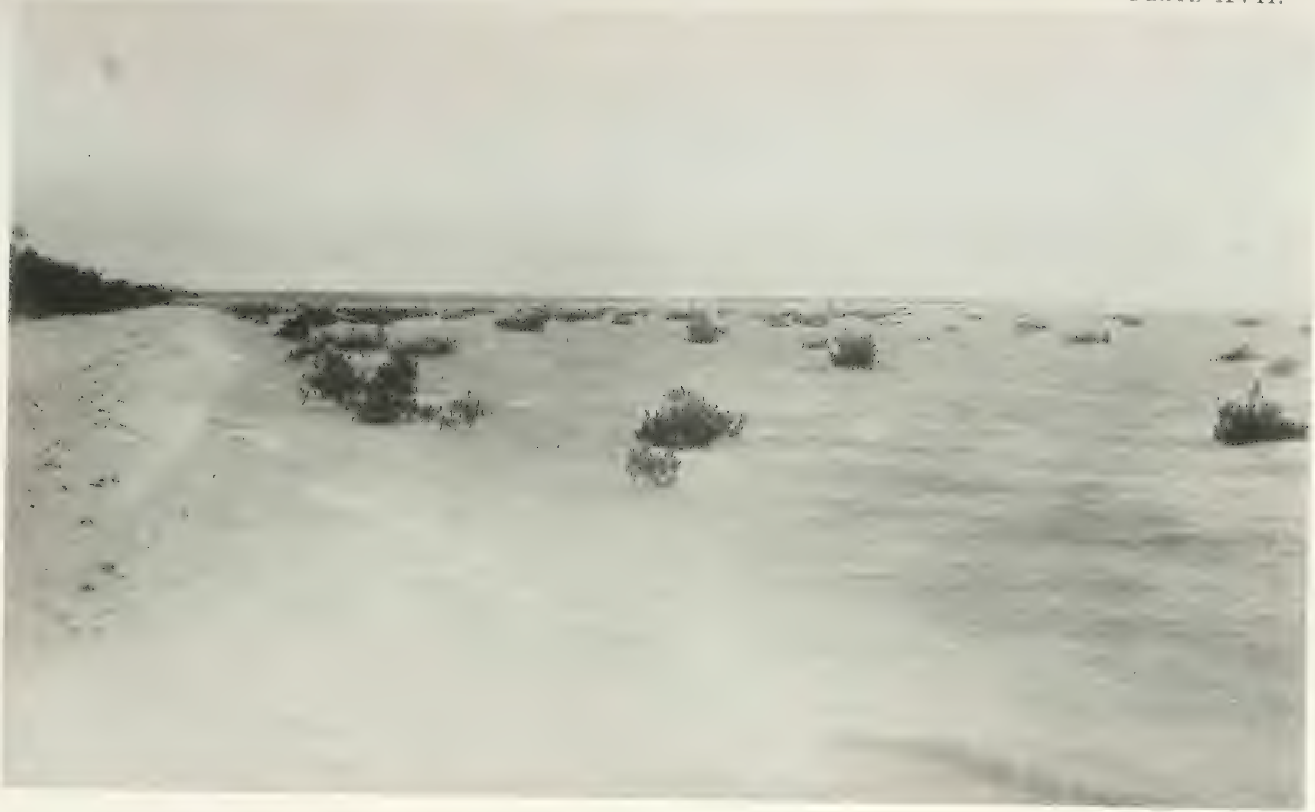
ARTOTYPE, E. BIERSTADT N. Y.

ÆOLIAN ROCKS. NASSAU.



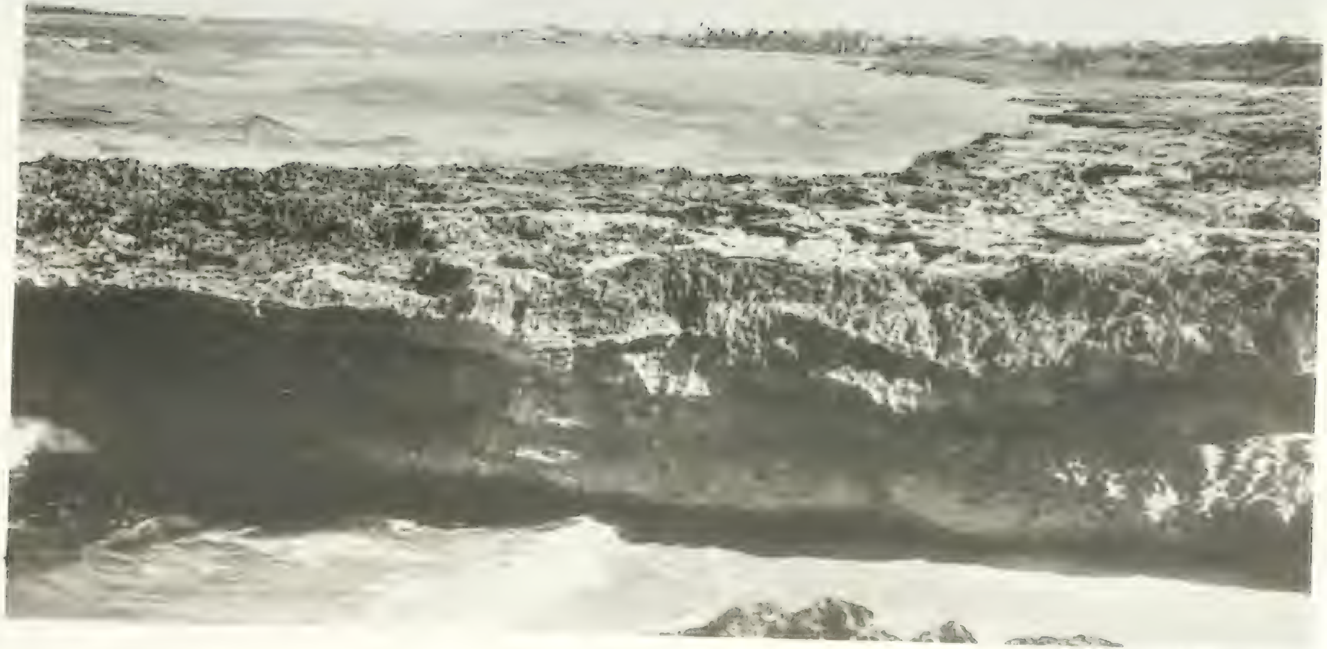
ARTOTYPE, E. BIERSTADT, N. Y.

DISTANT VIEW OF NASSAU.

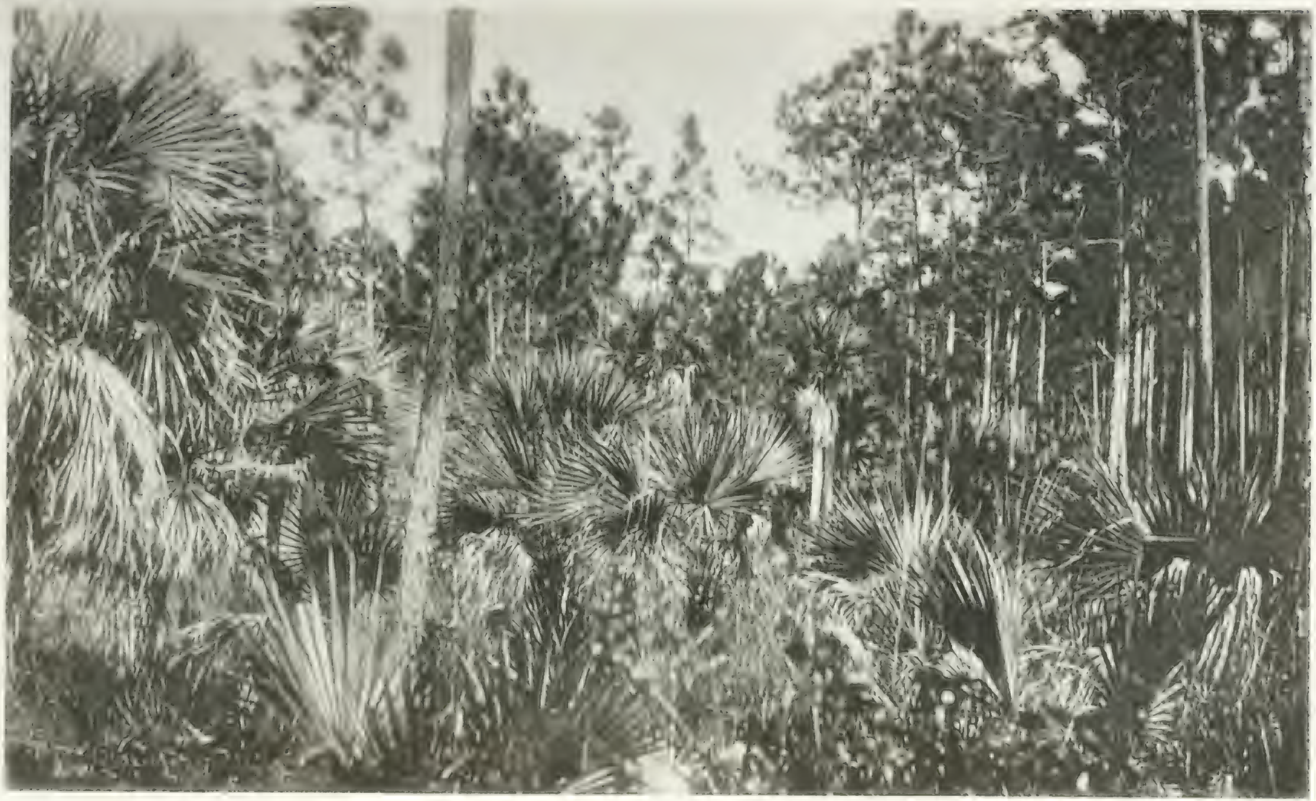


ARTOTYPE, E. BIERSTADT, N. Y

MANGROVE FLAT, NEW PROVIDENCE.

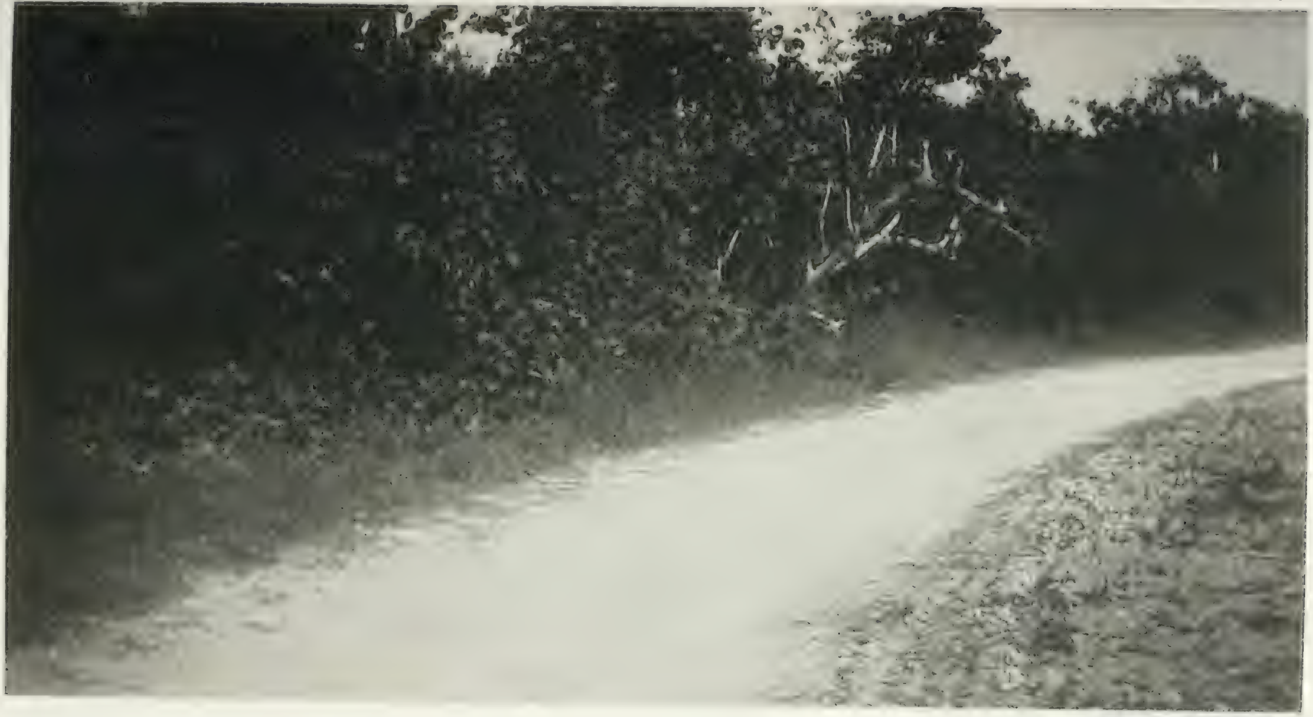


NORTH SHORE, NEW PROVIDENCE.



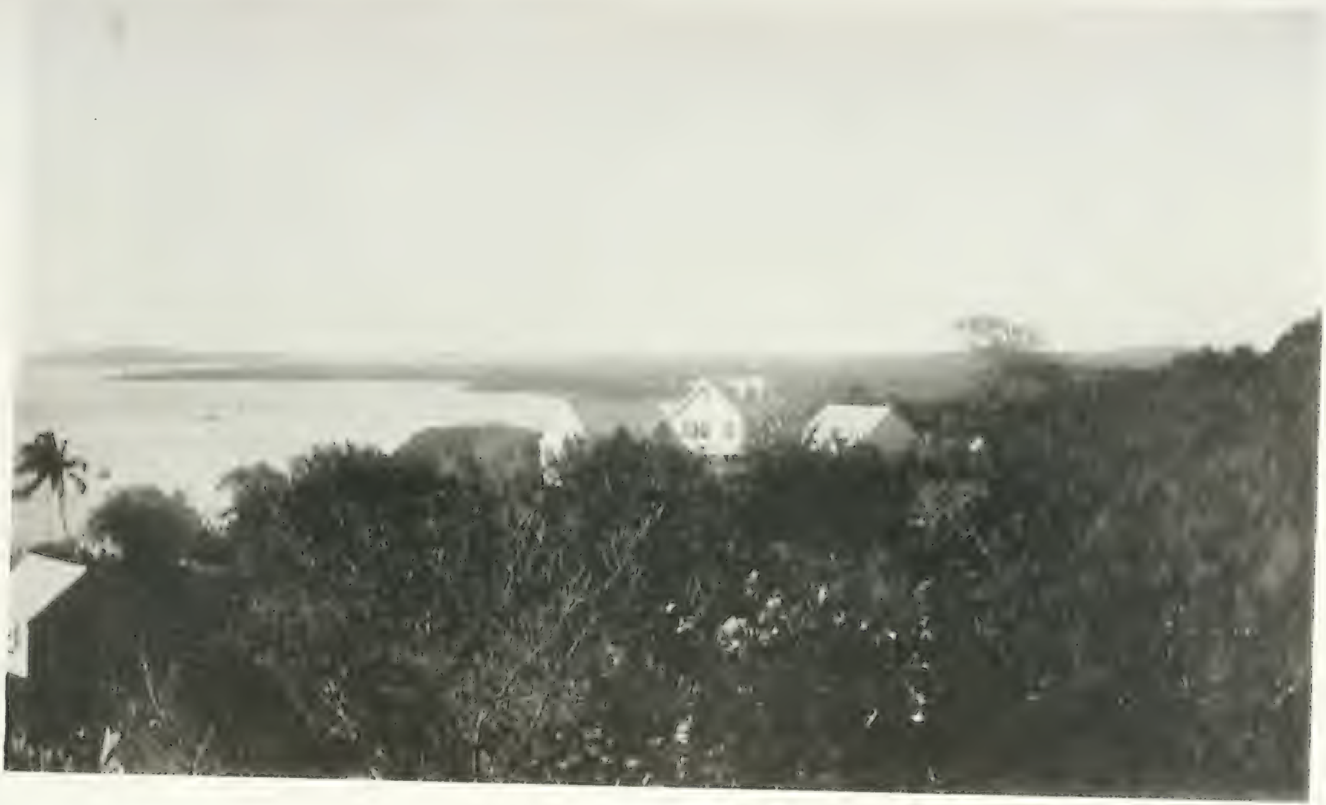
ARTOTYPE, E. BIERSTADT, N. Y.

INLAND VEGETATION. NEW PROVIDENCE.



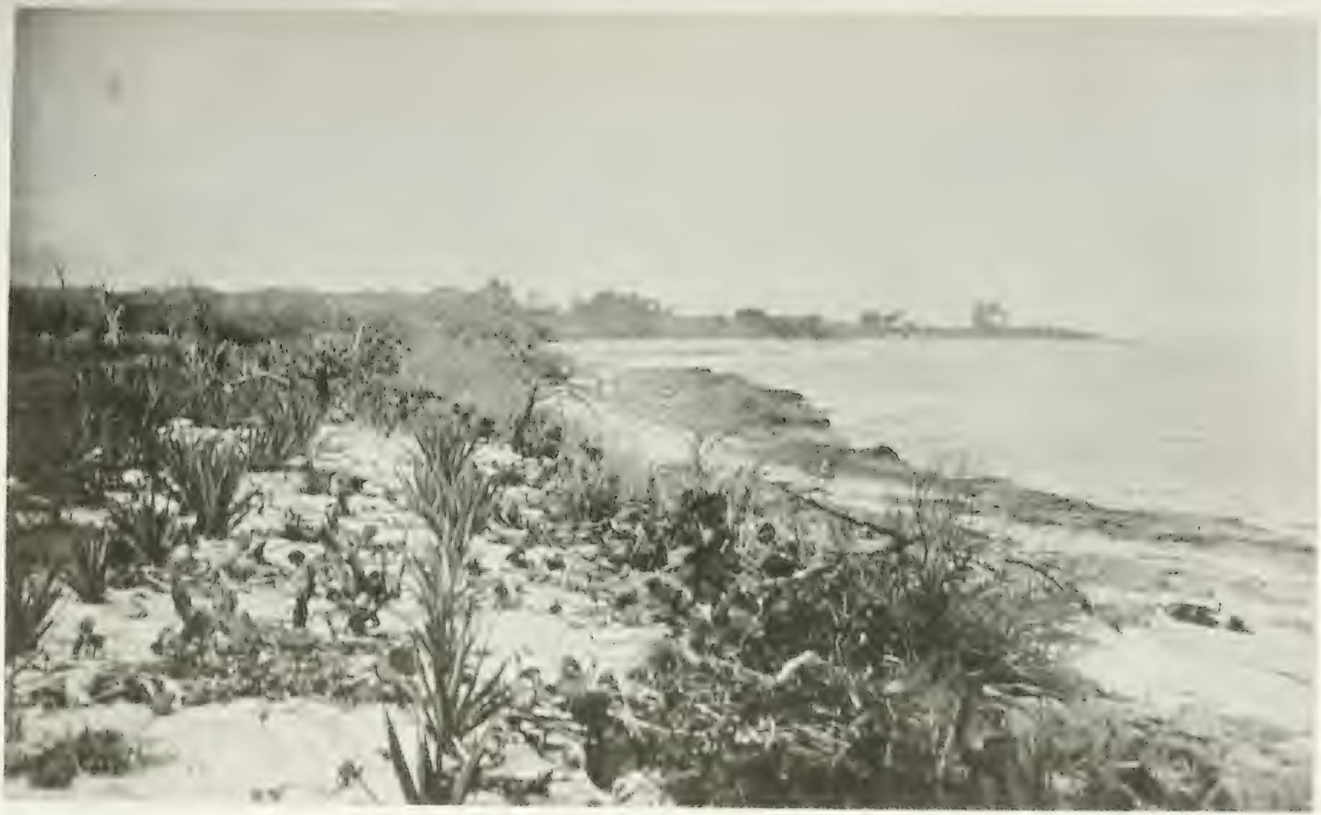
ARTOTYPE, E. BIERSTADT, N. Y.

SHORE VEGETATION, NEW PROVIDENCE.



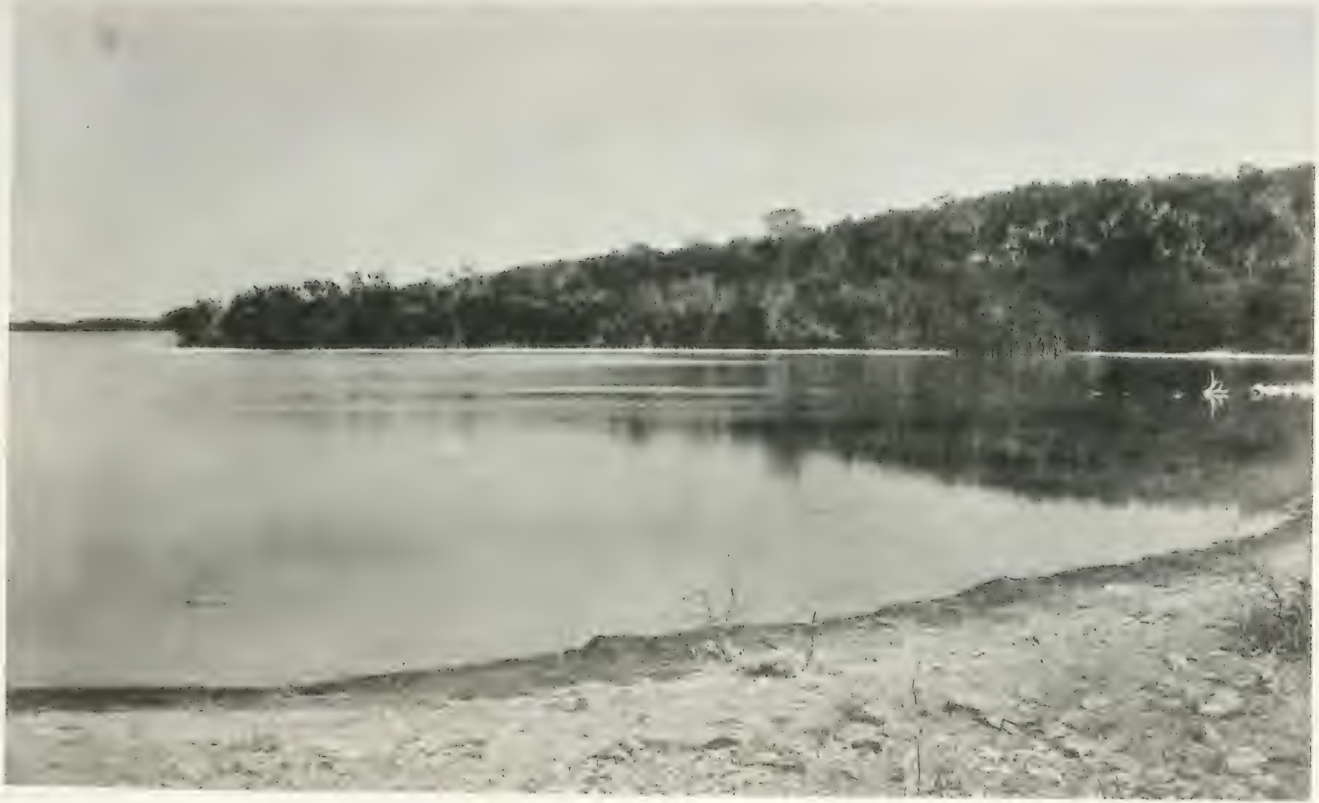
ARTOTYPE, E. BIERSTADT, N. Y.

GREEN TURTLE CAY.



ARTOTYPE, E. BIERSTADT, N. Y.

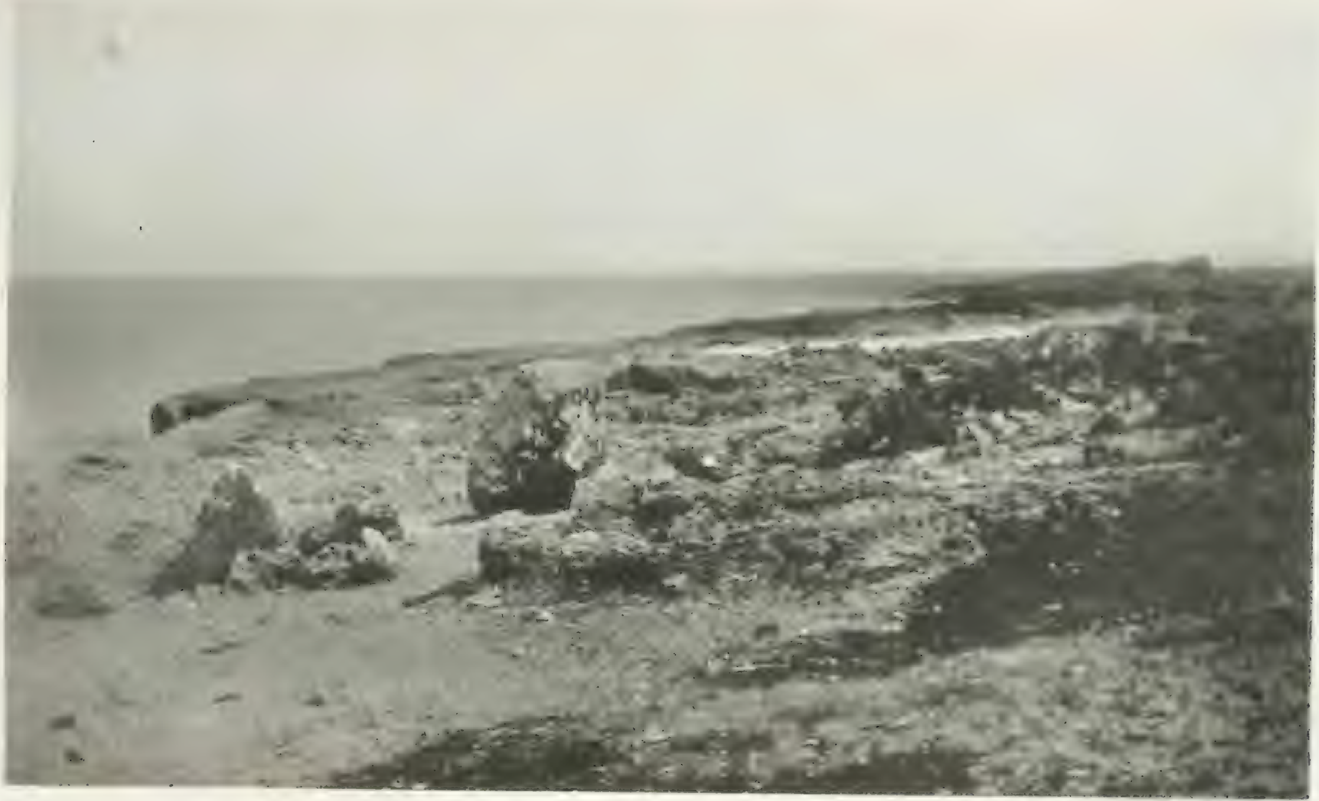
BEACH ON GREEN CAY.



ARTOTYPE, E. BIERSTADT, N.Y.

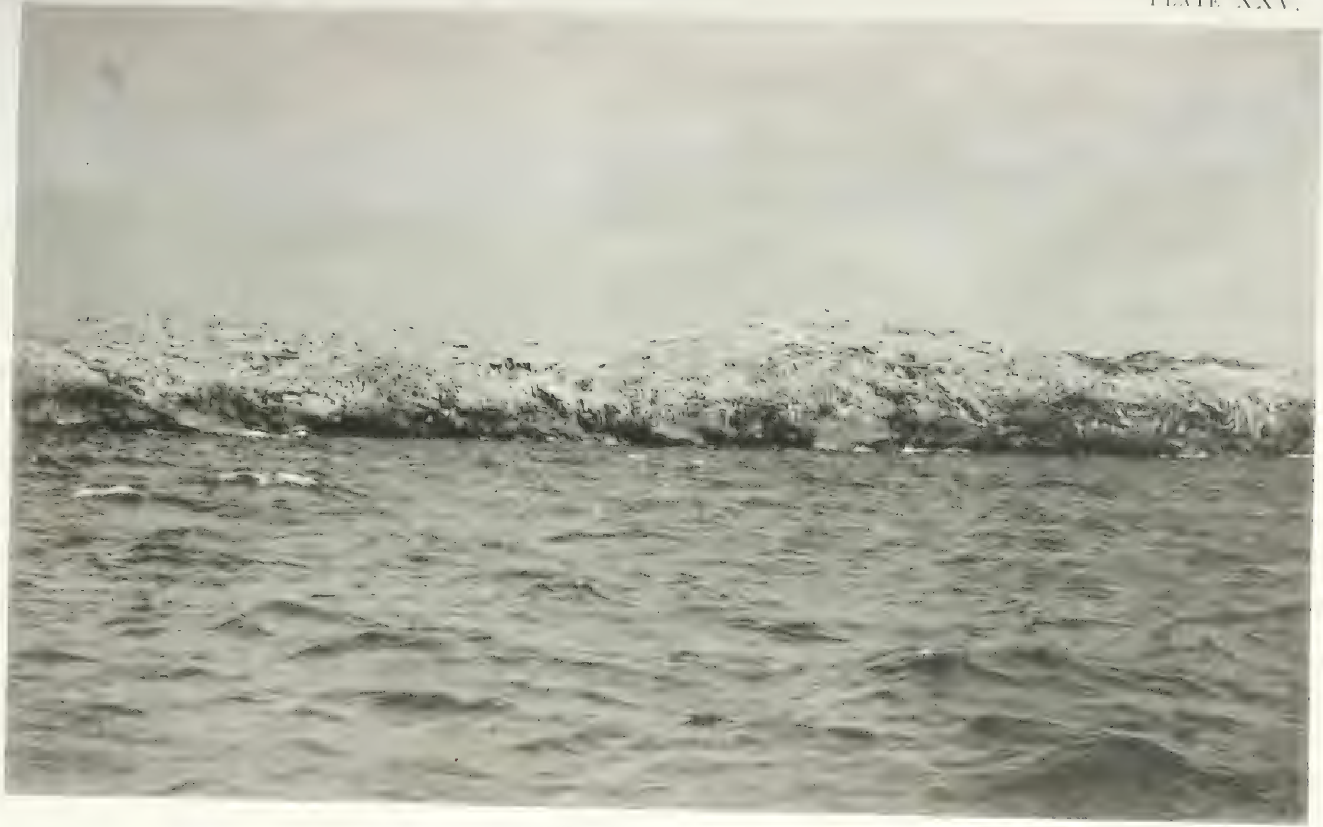
LAGOON, WATLINGS ISLAND.

PLATE XXIV.



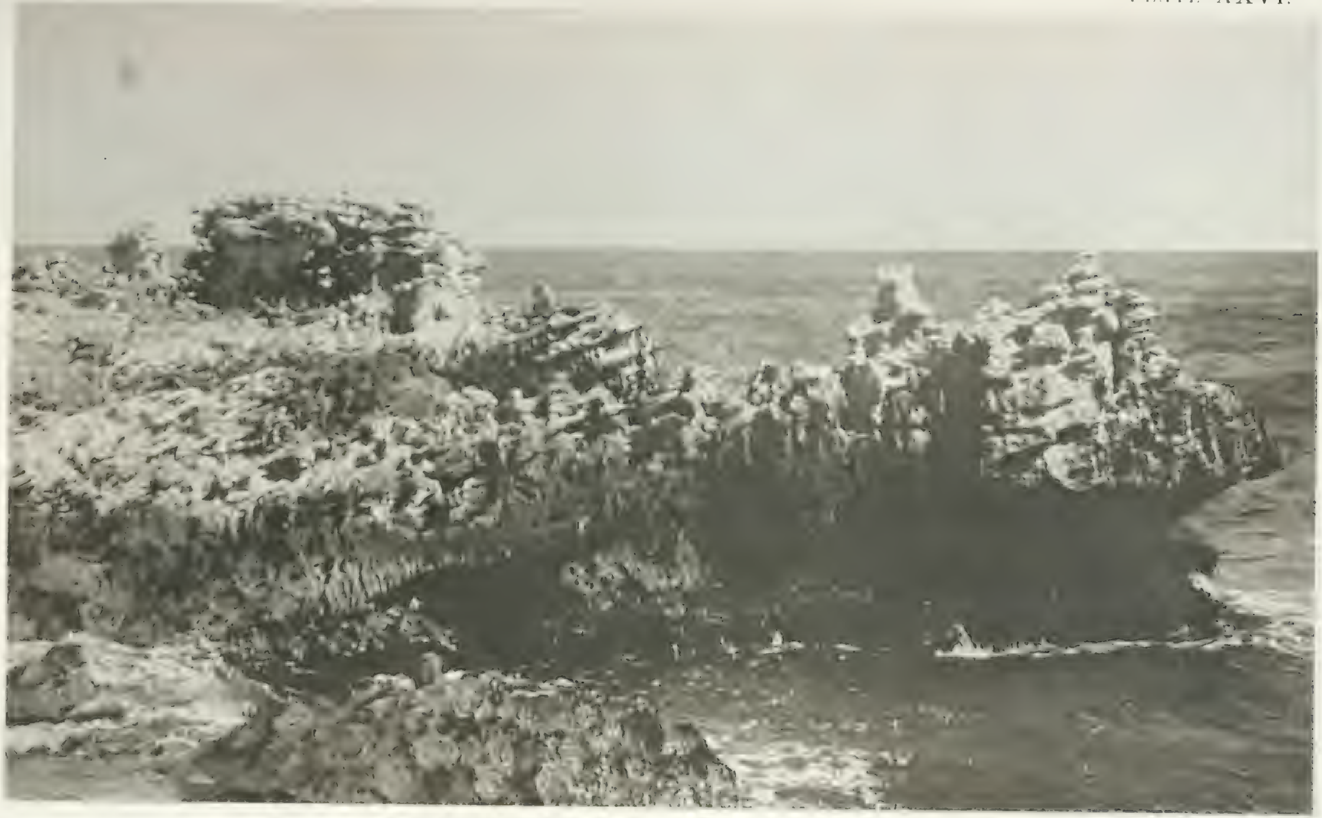
ARTOTYPE, E. BIERSTADT, N. Y.

NORTH SHORE OF GREAT ISAAC.



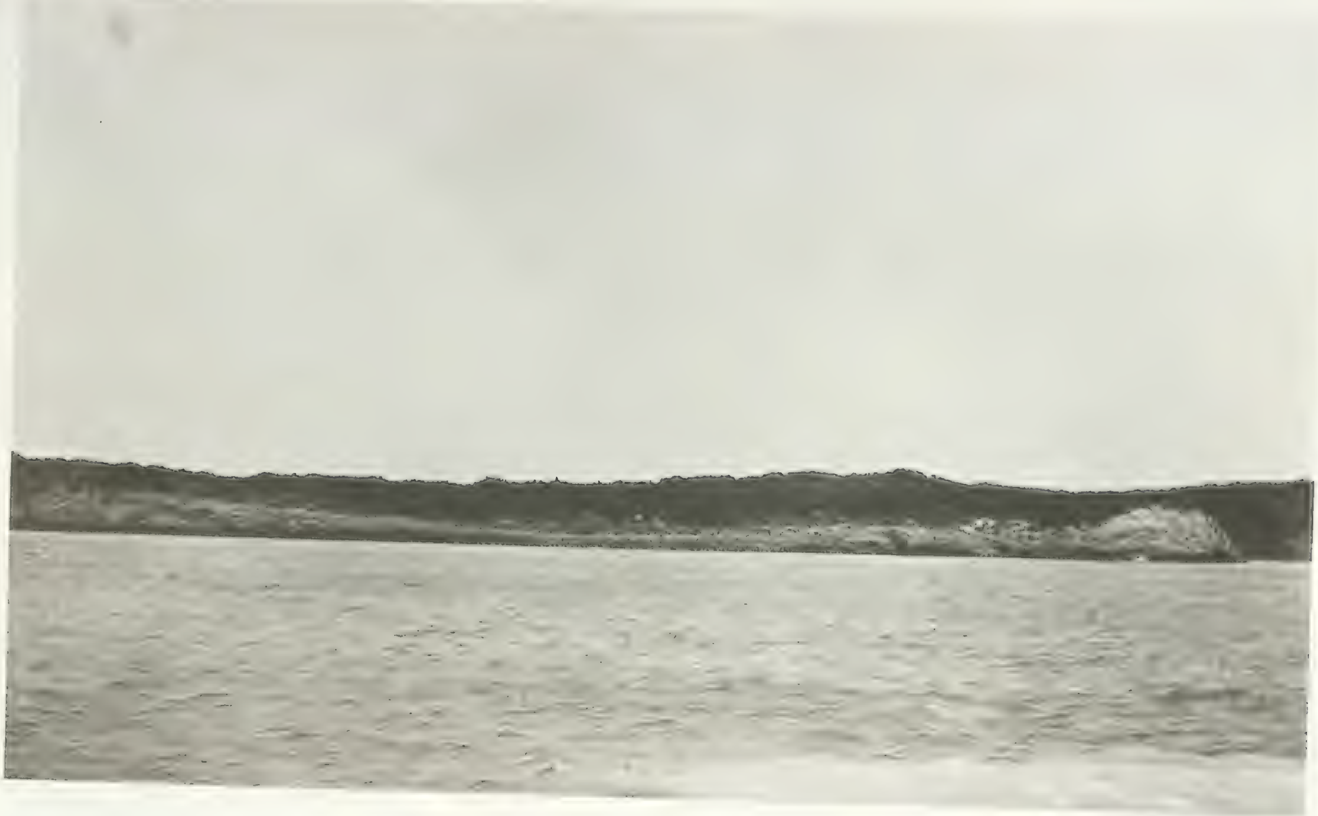
ARTOTYPE. E. BIERSTADT, N. Y.

SOUTH SHORE OF GREAT ISAAC.



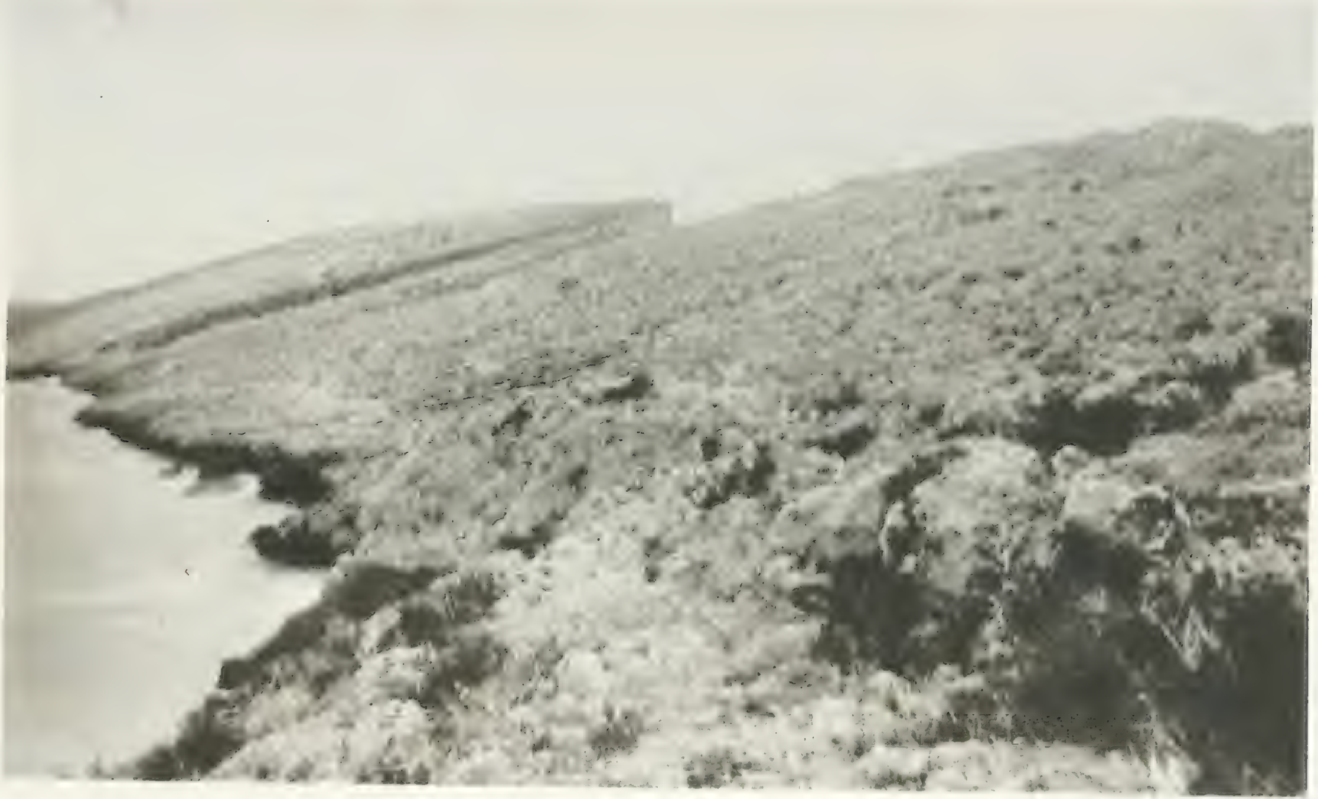
ARTOTYPE. E. BIERSTADT. N. Y.

SOUTH SHORE OF GREAT ISAAC.



ARTOTYPE, E. BIERSTADT, N. Y.

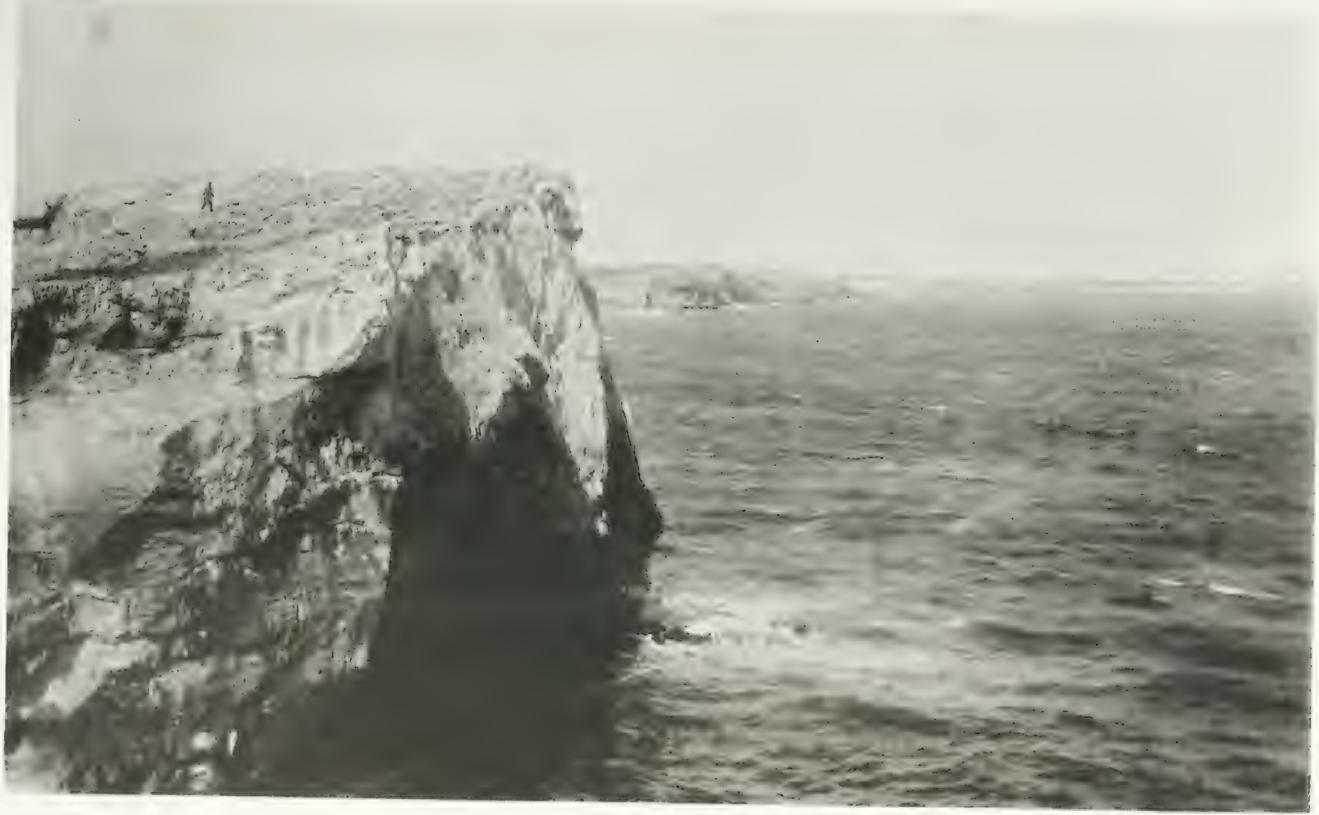
WEST COAST OF ELEUTHERA.



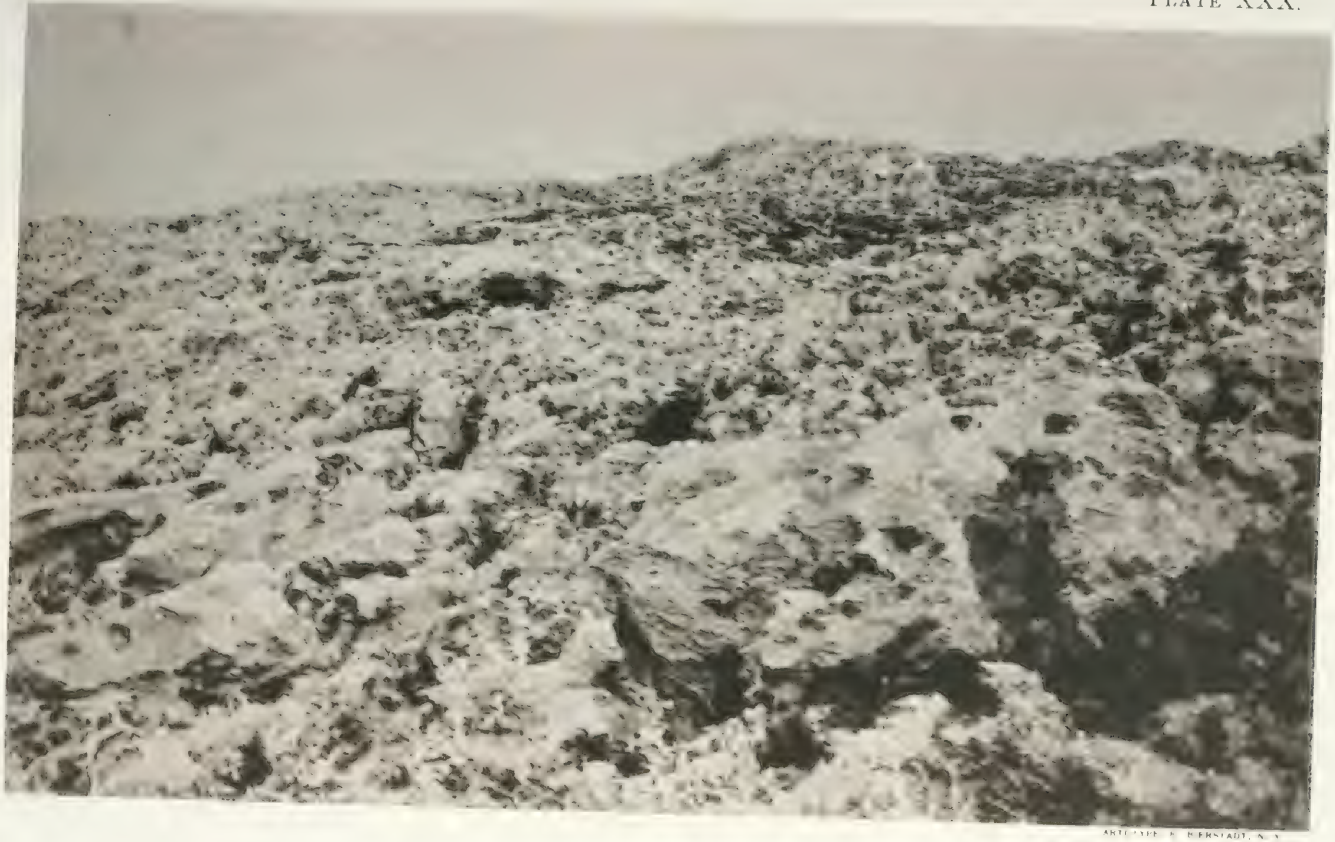
ARTOTYPE, E. BIENSTADT, N. Y.

WEST FACE OF NORTHERN ELEUTHERA.

PLATE XXIX.

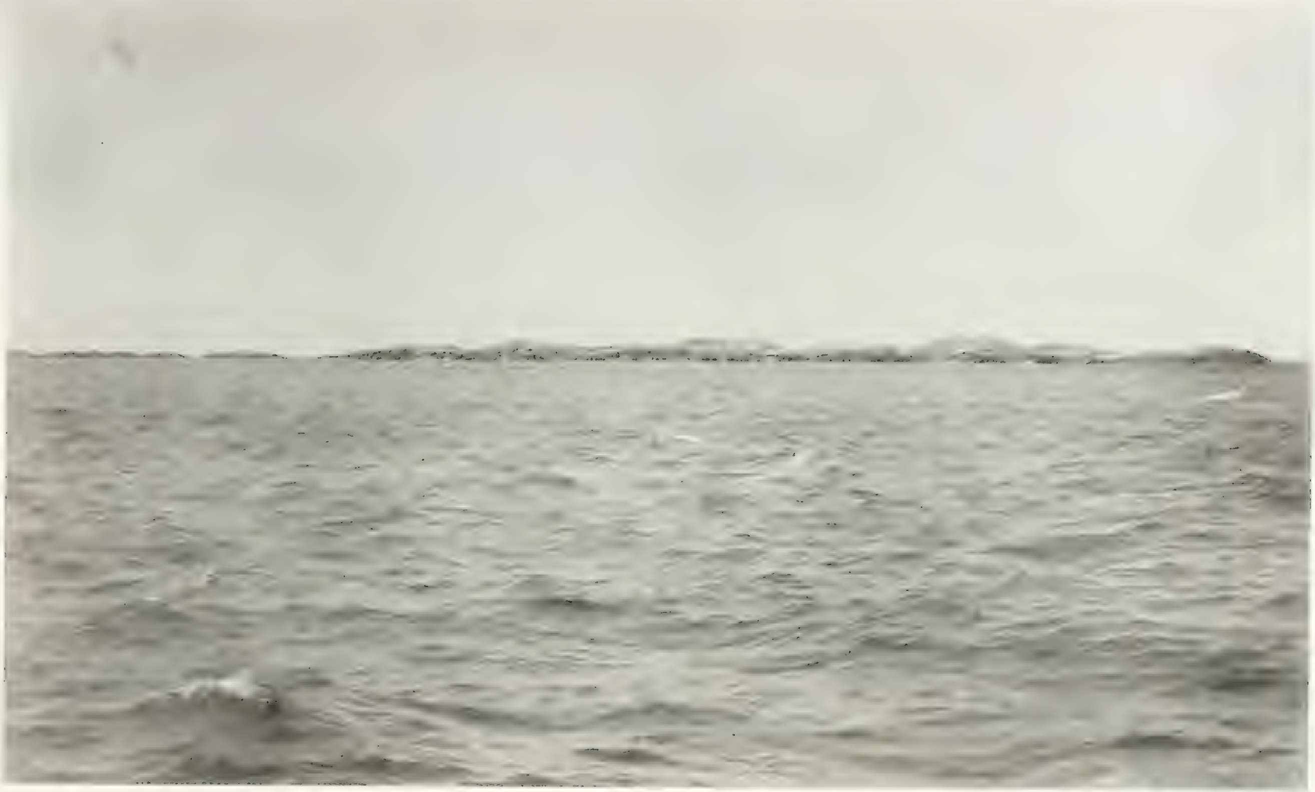


CLIFFS. ELEUTHERA.



ARTOTYPE E. BIERSTADT, N.Y.

HONEYCOMBED ROCKS. ELEUTHERA.

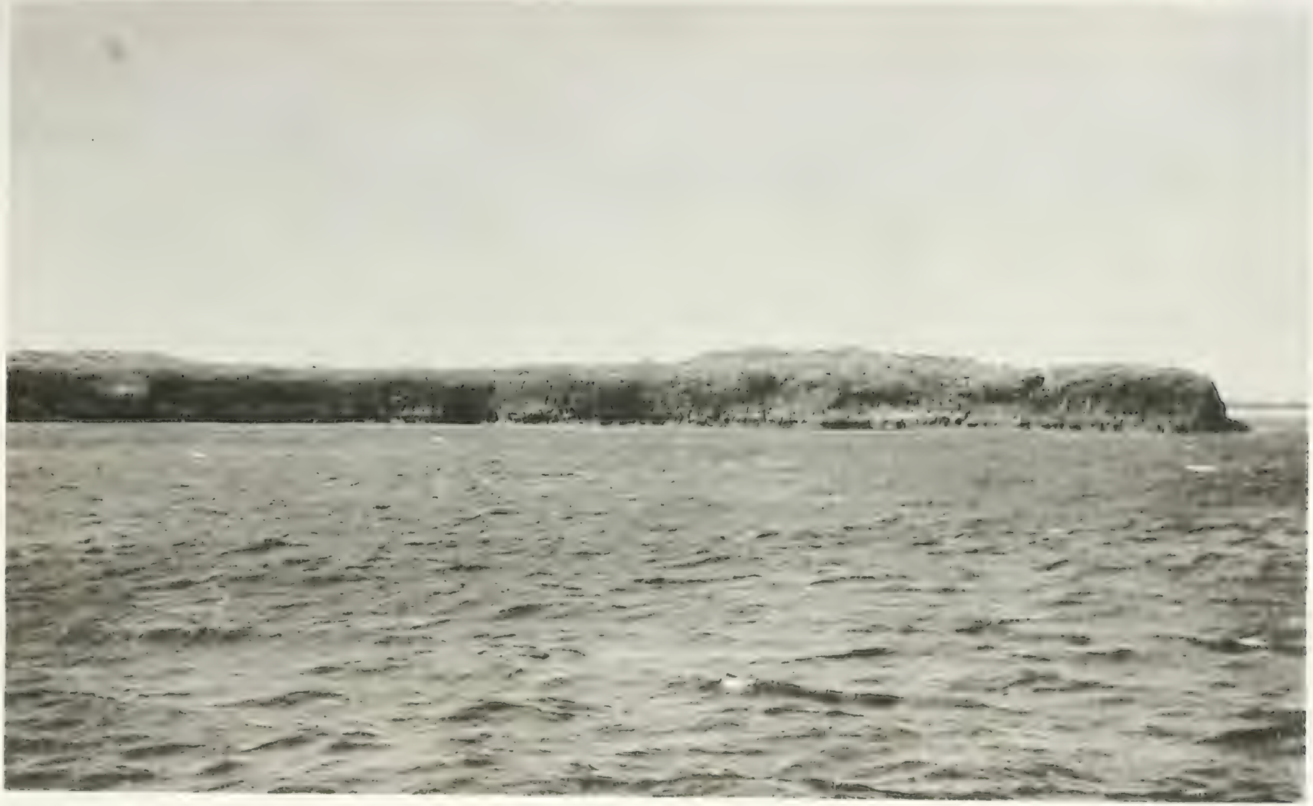


ARTOTYPE, E. BIERSTADT, N. Y.

ELBOW CAYS.

ART TYPE E. BIERSTADT, N. Y.

BOOBY ISLAND.

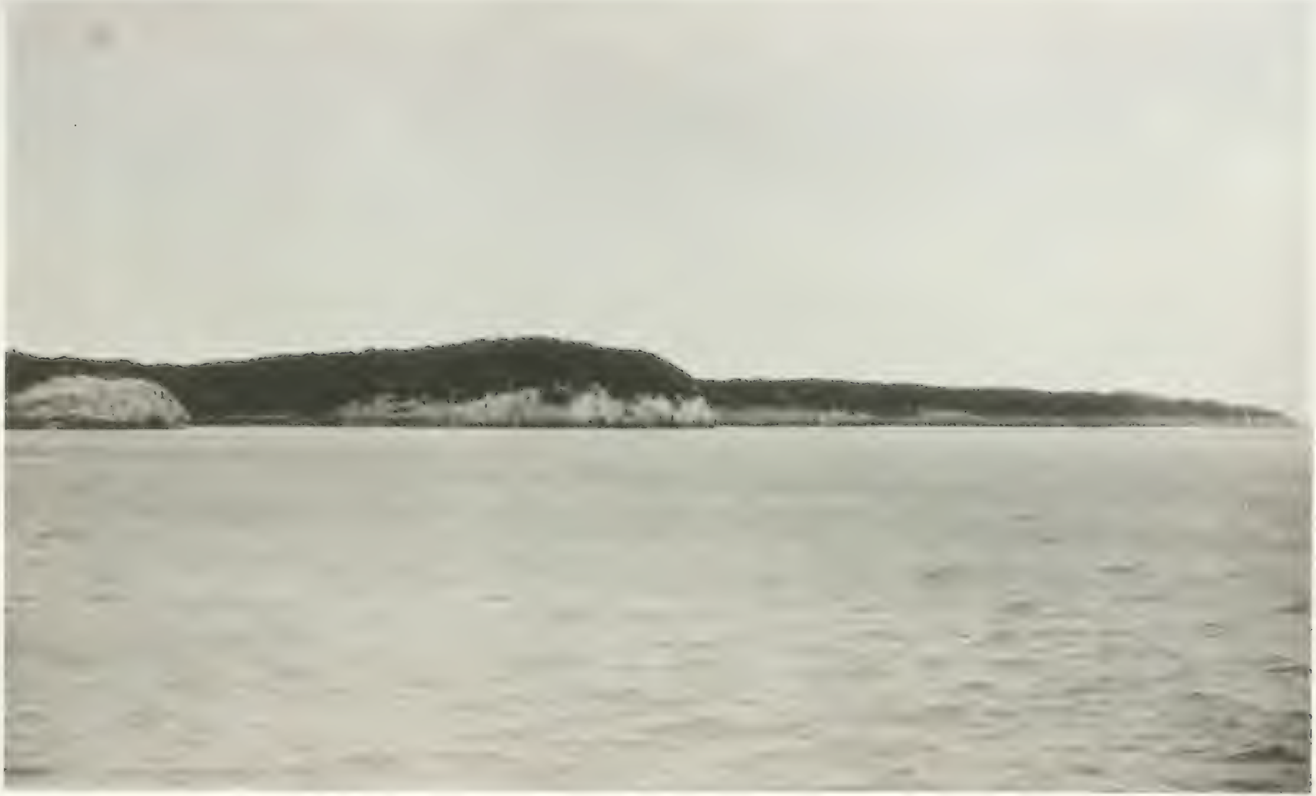


ARTOTYPE, E. BIERSTADT, N.Y.

MORGAN'S BLUFF, ANDROS.

ARTOTYPE, E. BIERSTADT, N

WEST SHORE, CAT ISLAND.



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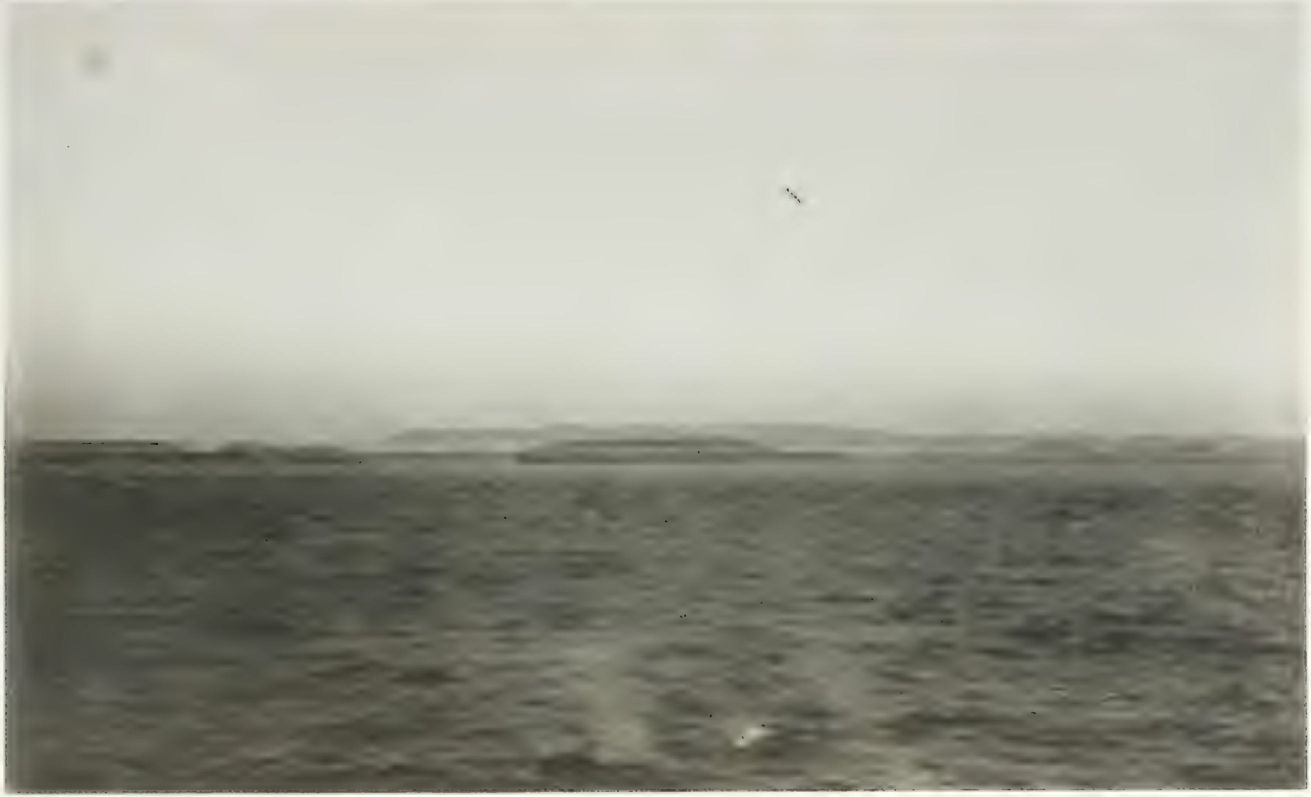
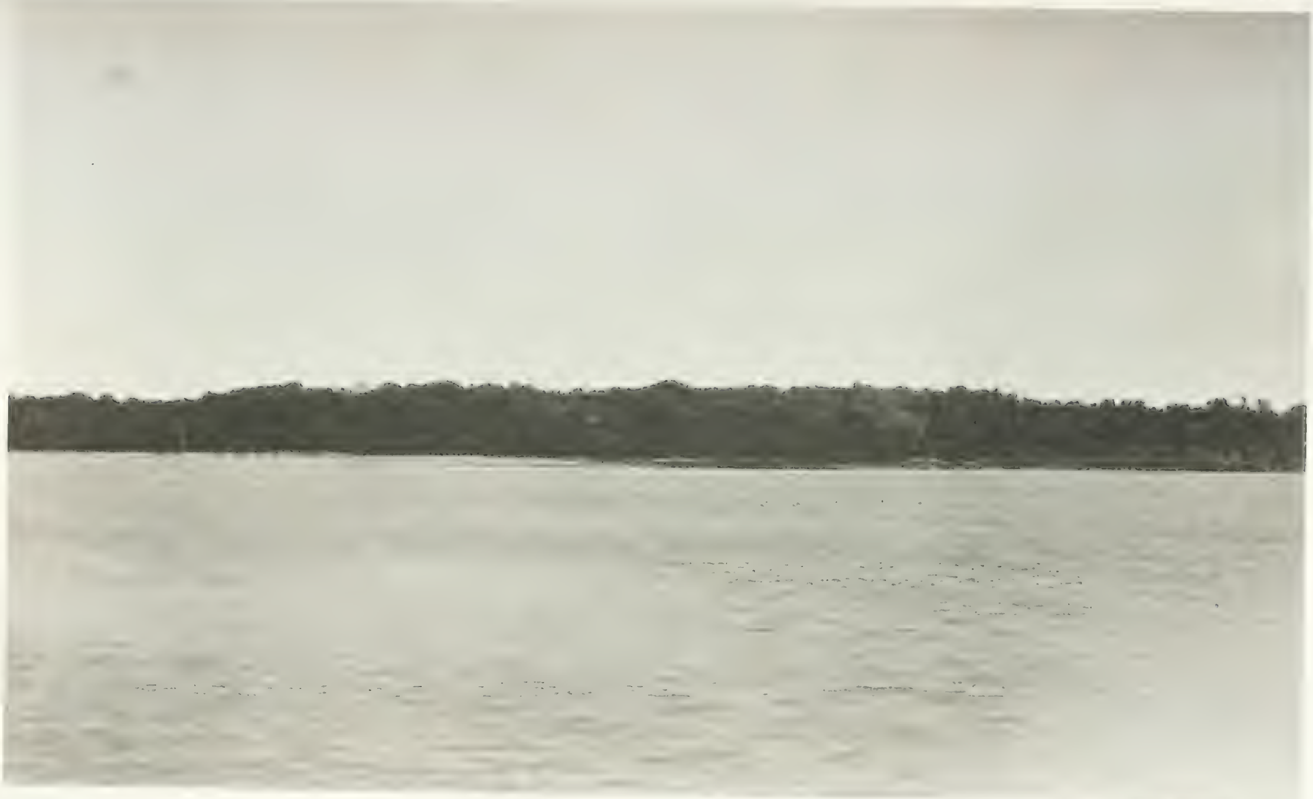
FLAMINGO CAY.



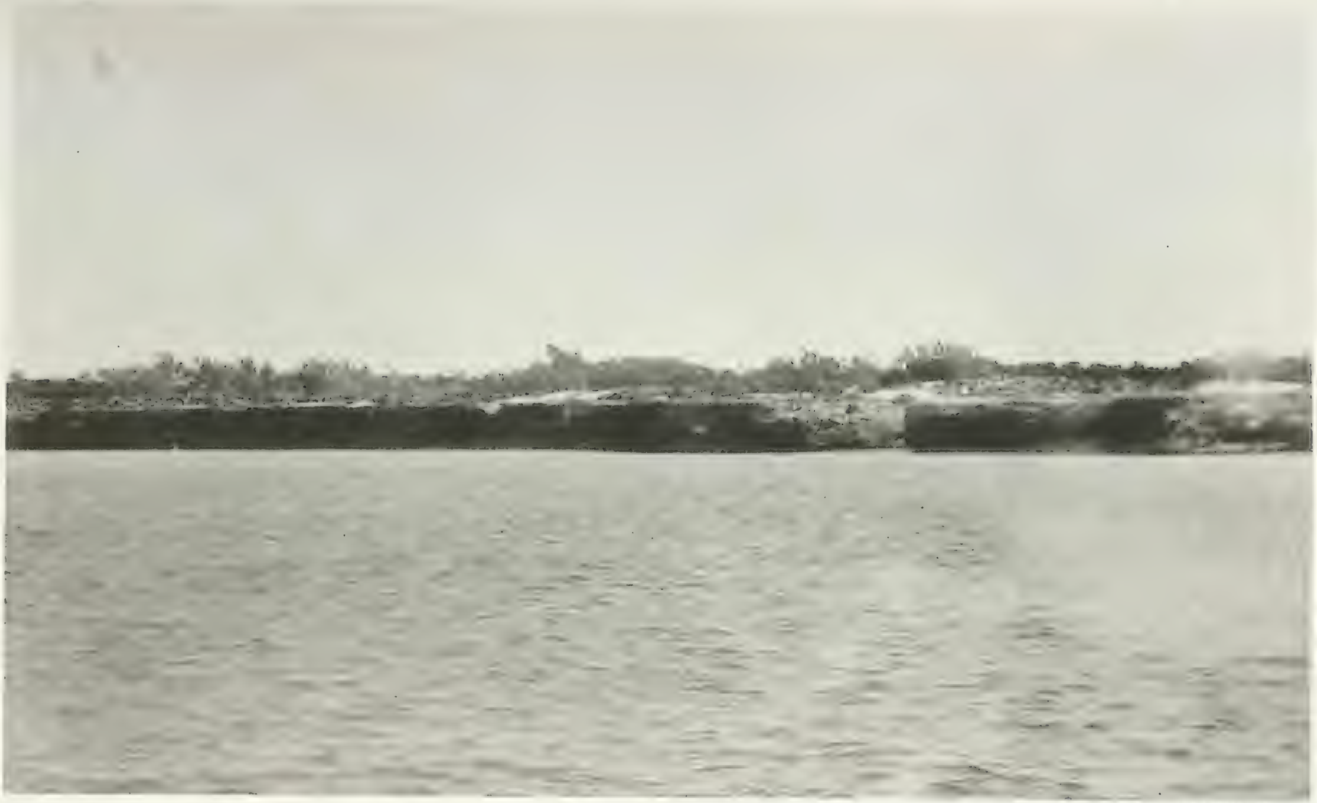
ARTOTYPE, E. BIERSTADT, N. Y.

CONCH CUT.

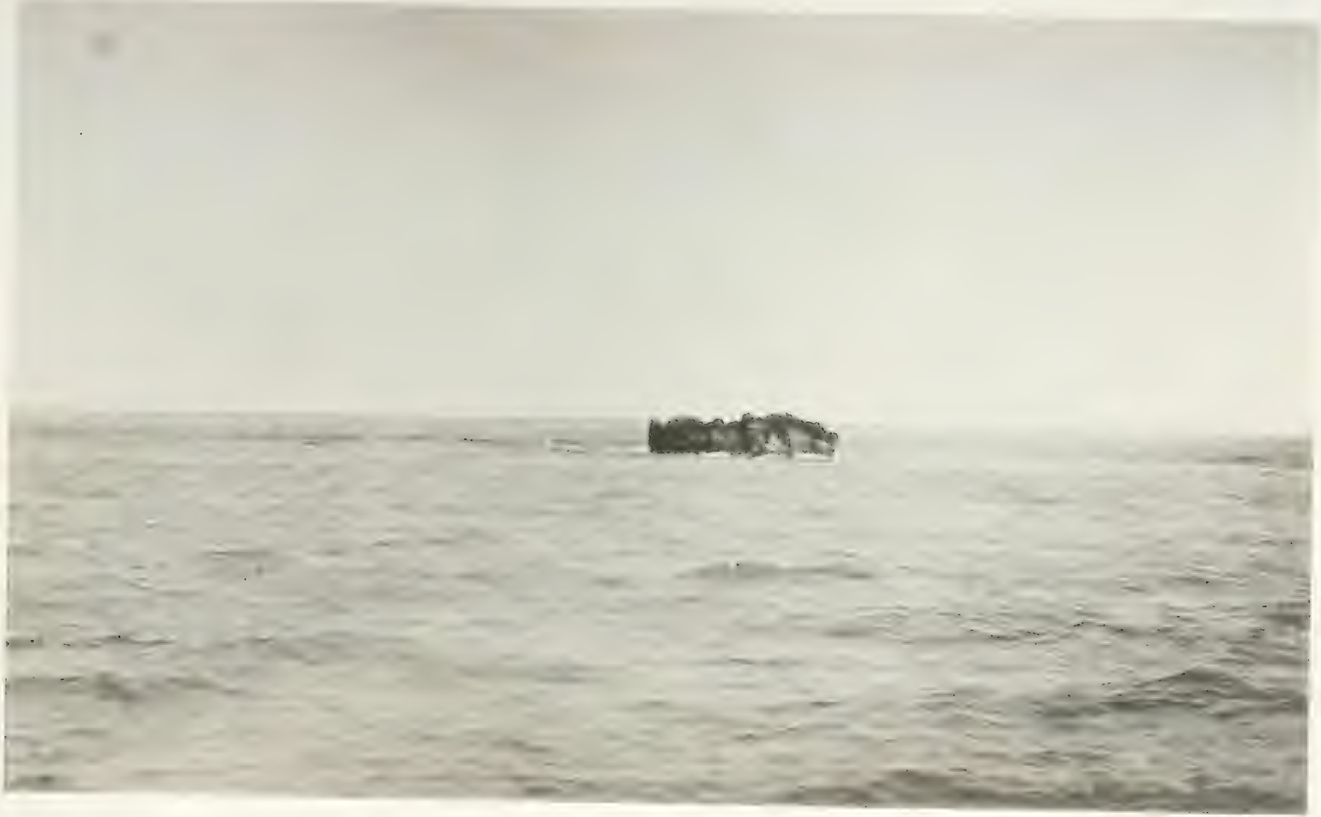


ARTOTYPE, E. BIERSTADT, N. Y.

WEST SHORE, CROOKED ISLAND.

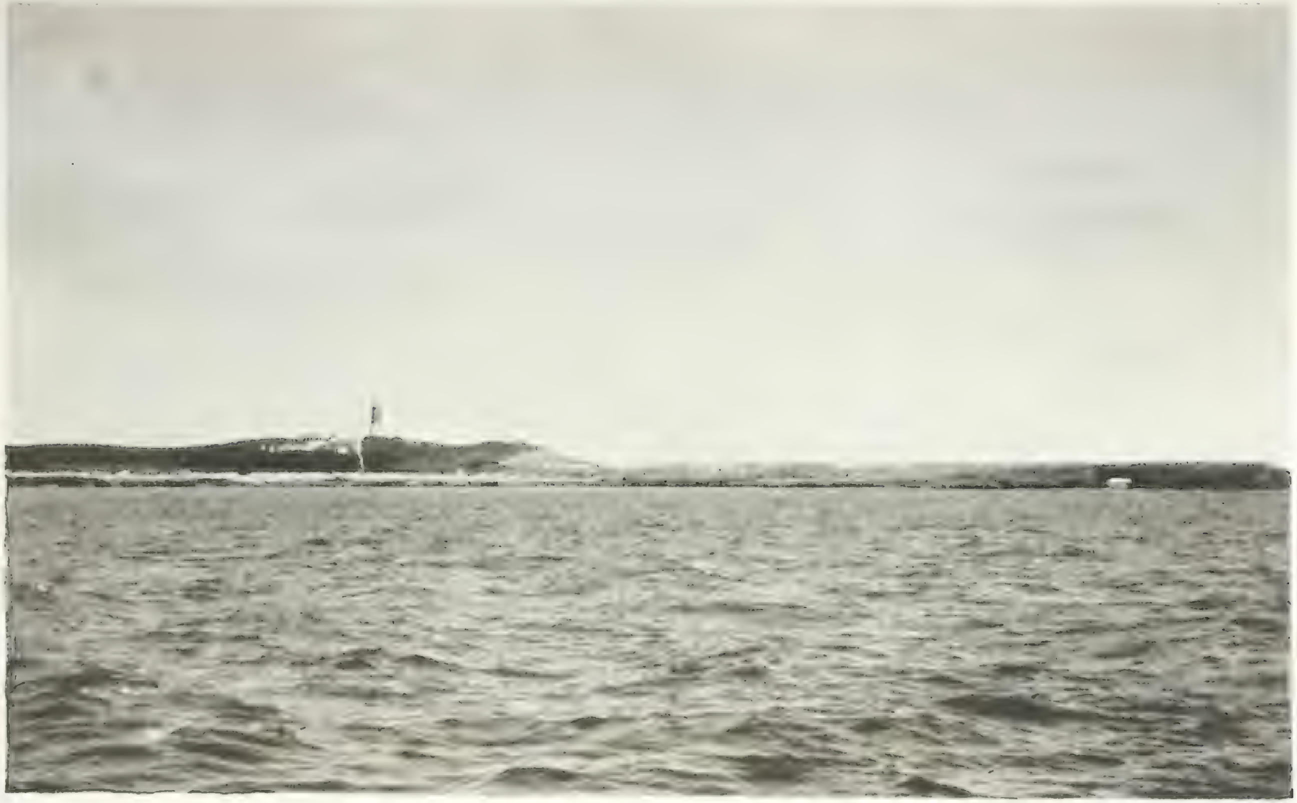


WEST SHORE, FORTUNE ISLAND.



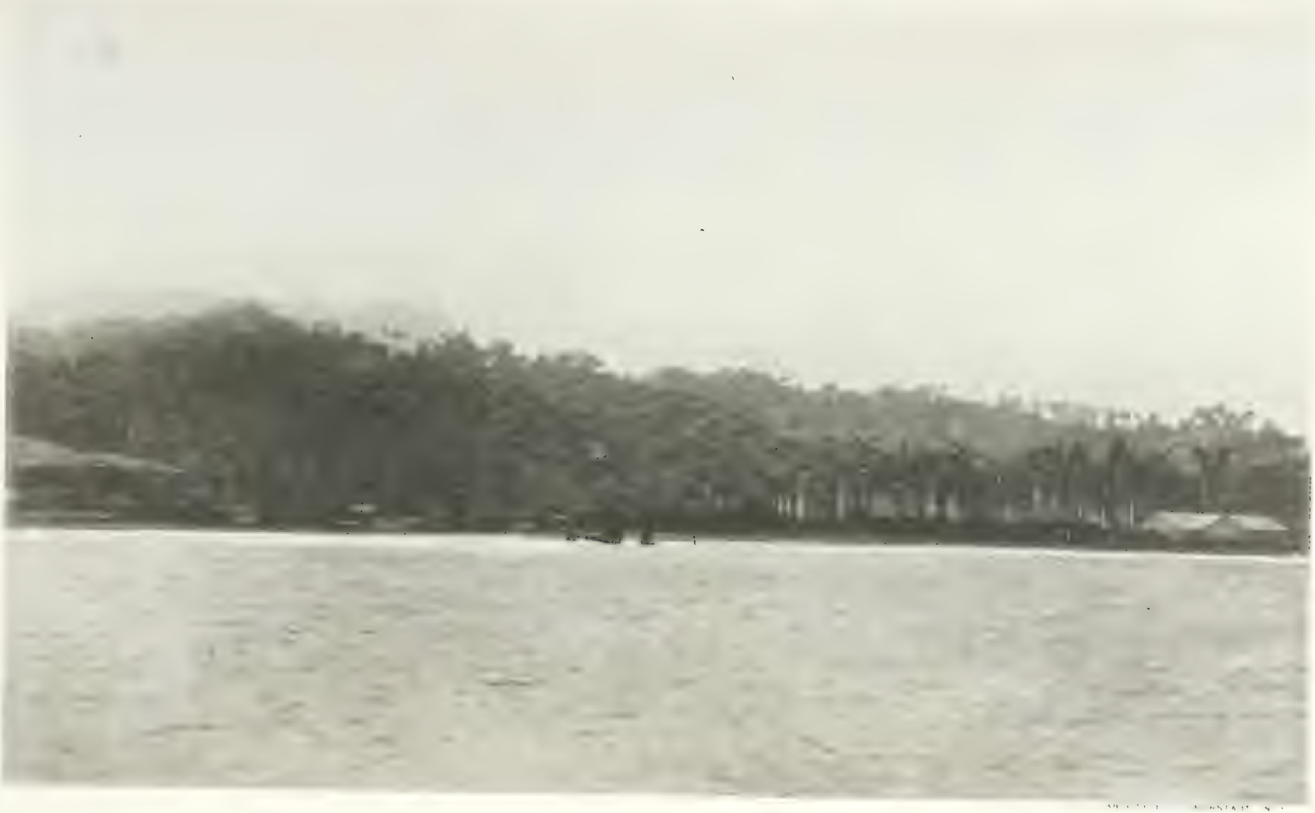
ARTOTYPE, E. BIERSTADT, N. Y.

MEMORY ROCK.

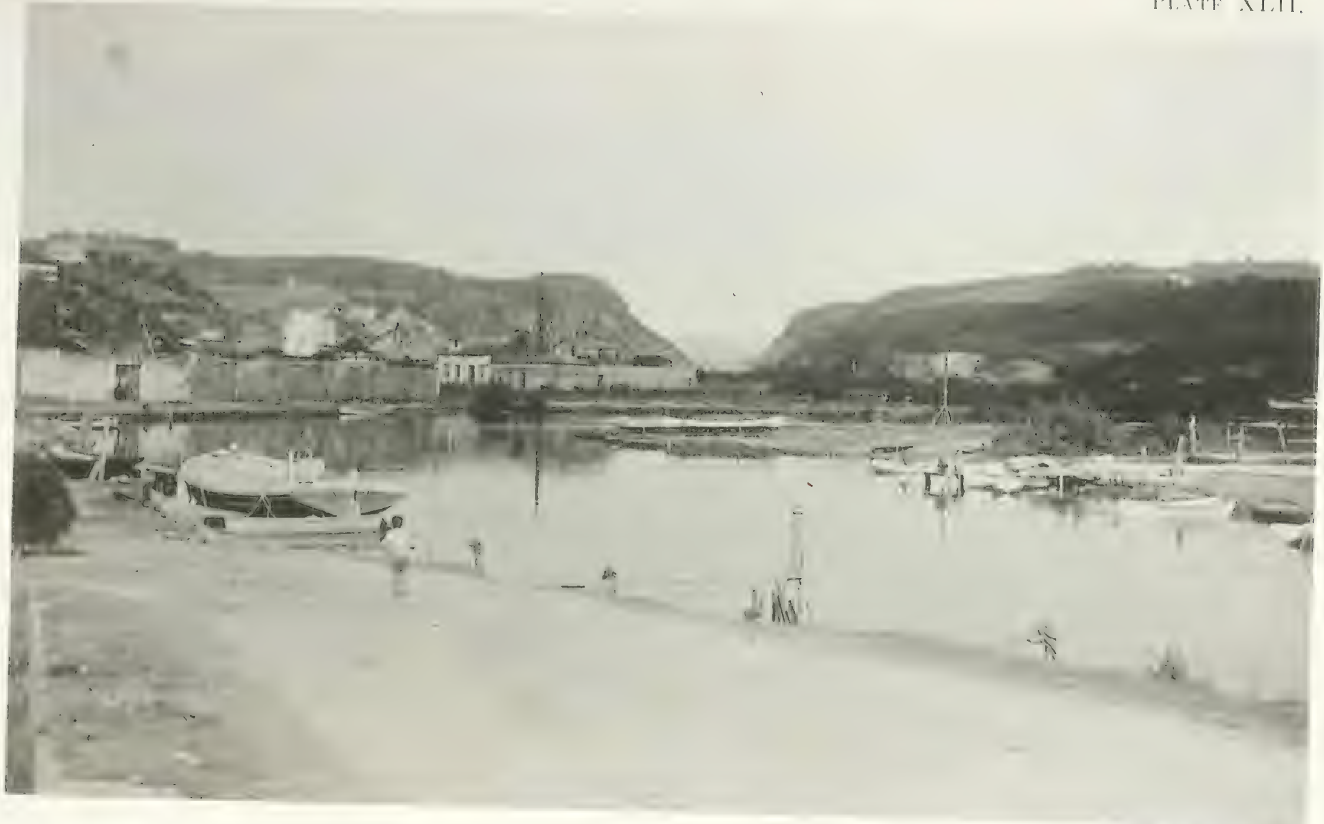


ARTOTYPE, E. BIERSTADT, N. Y

GREAT ABACO LIGHT.

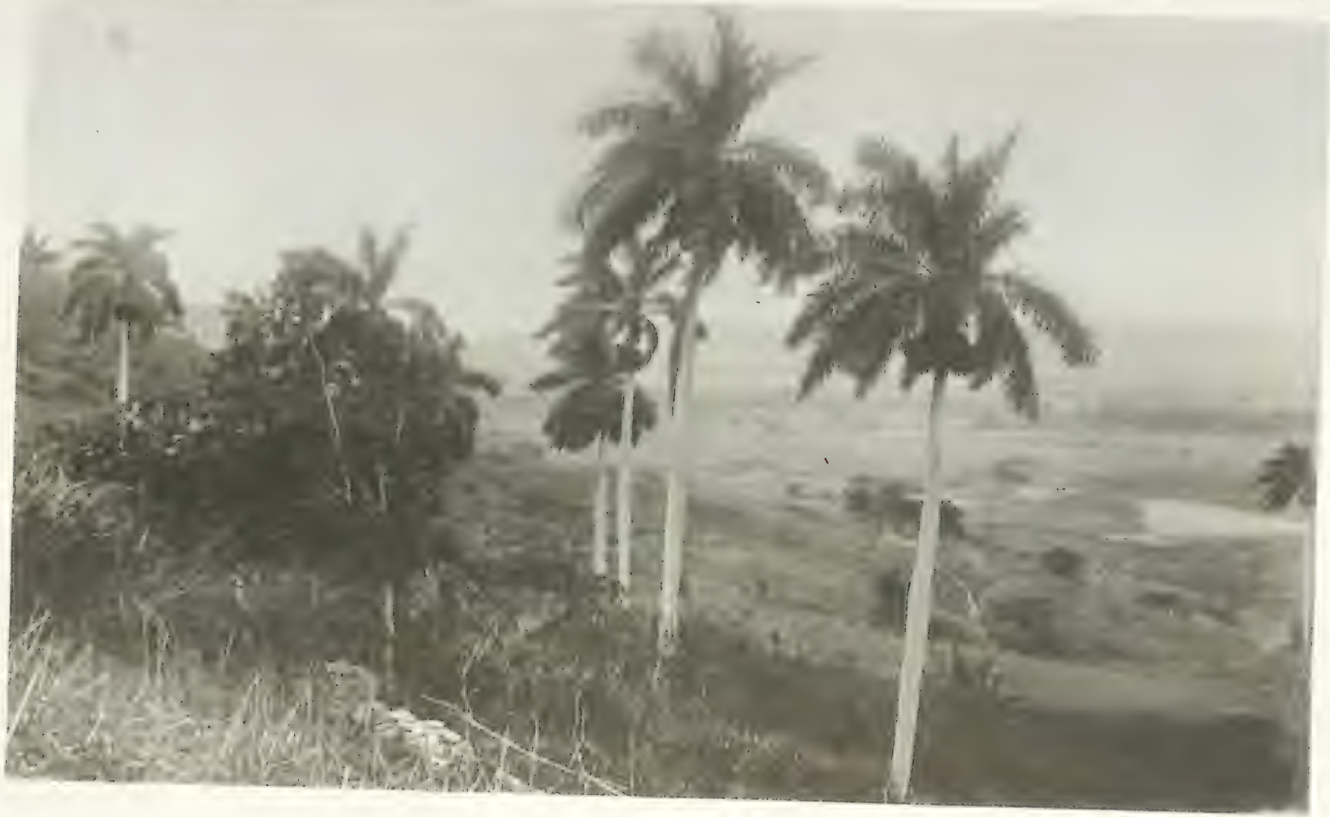


EL YUNQUE.



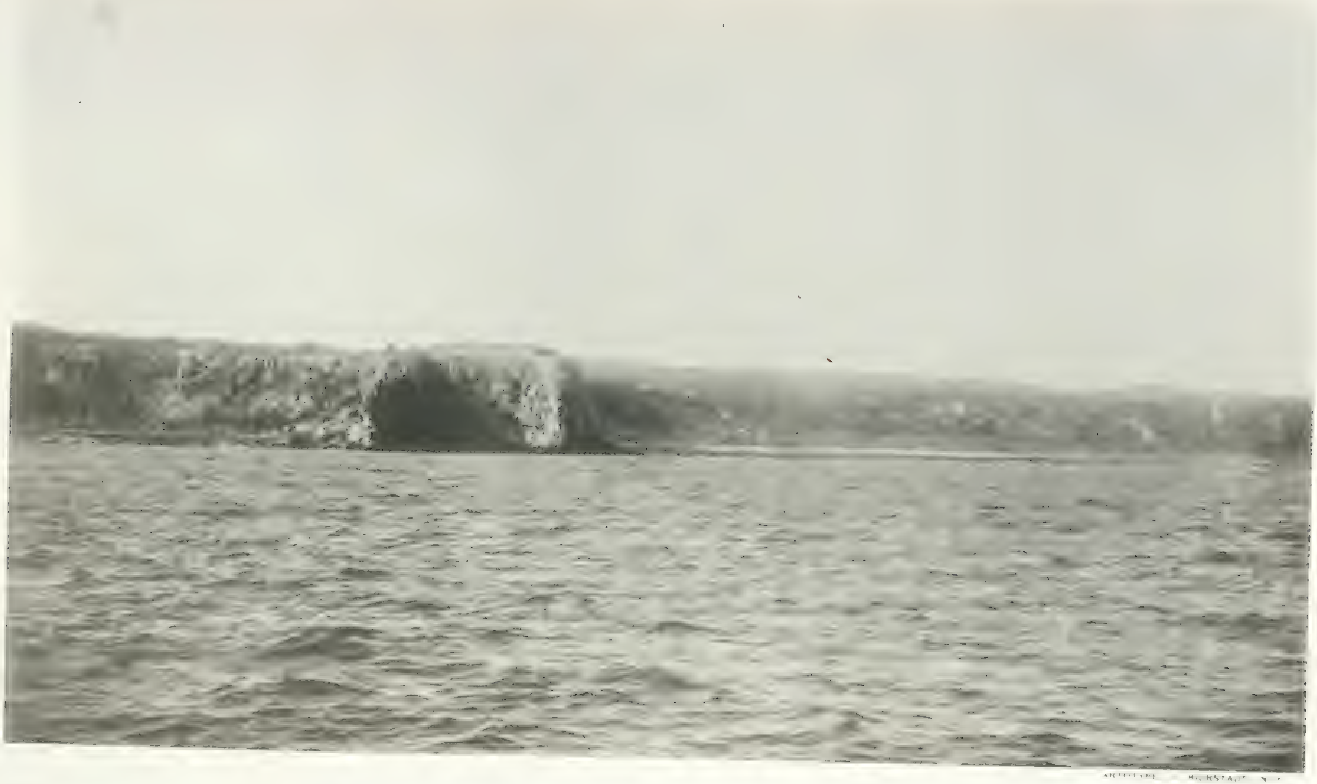
ARTOTYPE, E. BIERSTADT, N. Y.

YUMURI CAÑON.



ARTOTYPE, E. BIERSTADT, N. Y.

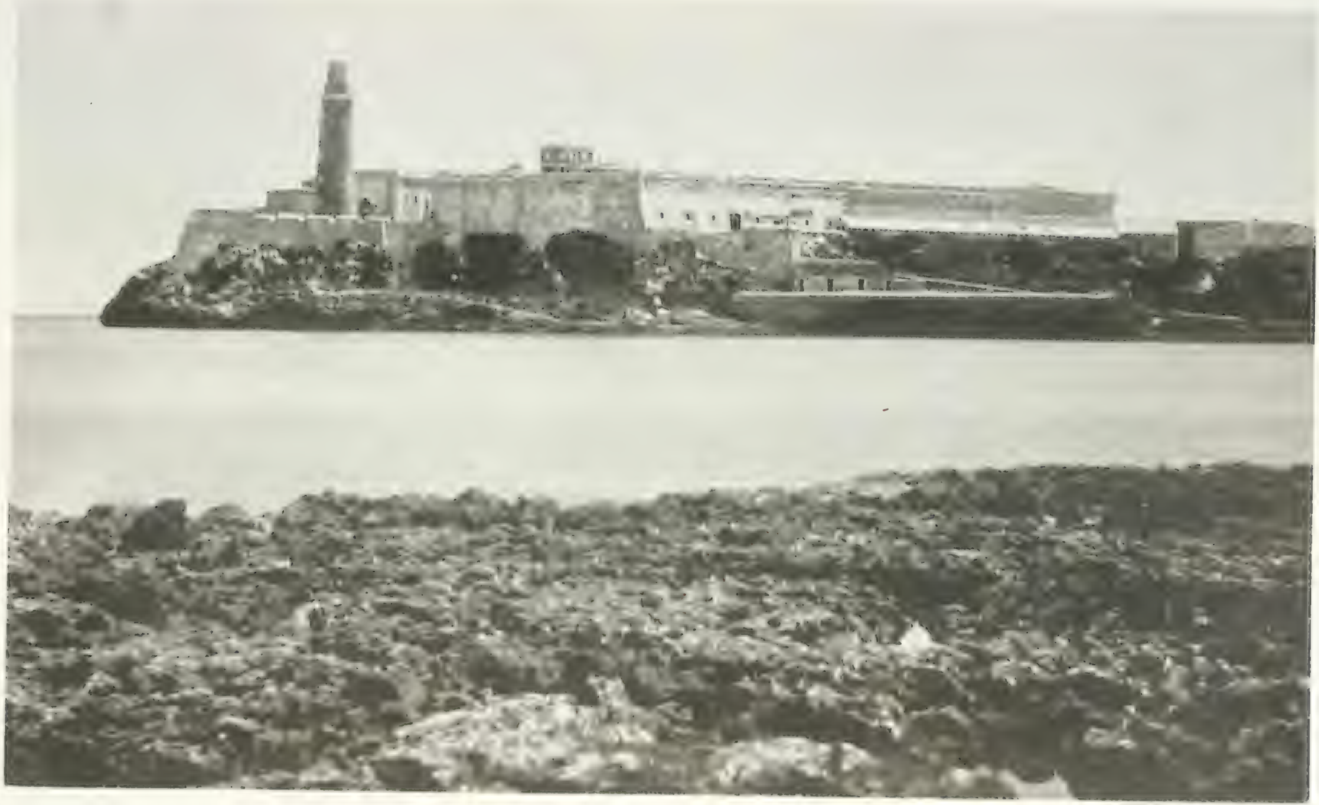
YUMURI VALLEY.



ARTOTYPE, BIERSTADT, N.Y.

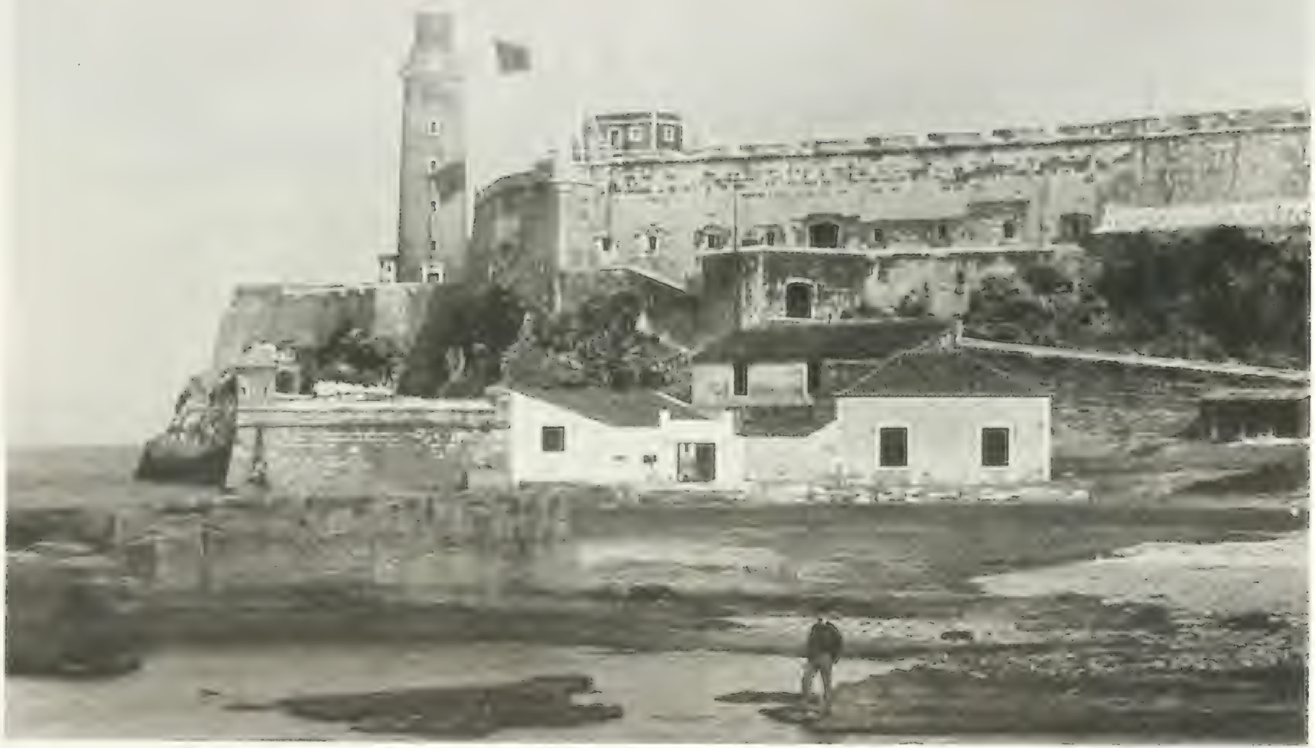
ELEVATED REEF, NORTH SHORE OF CUBA.

Plate XLV.



ARTOTYPE, E. BIERSTADT, N.Y.

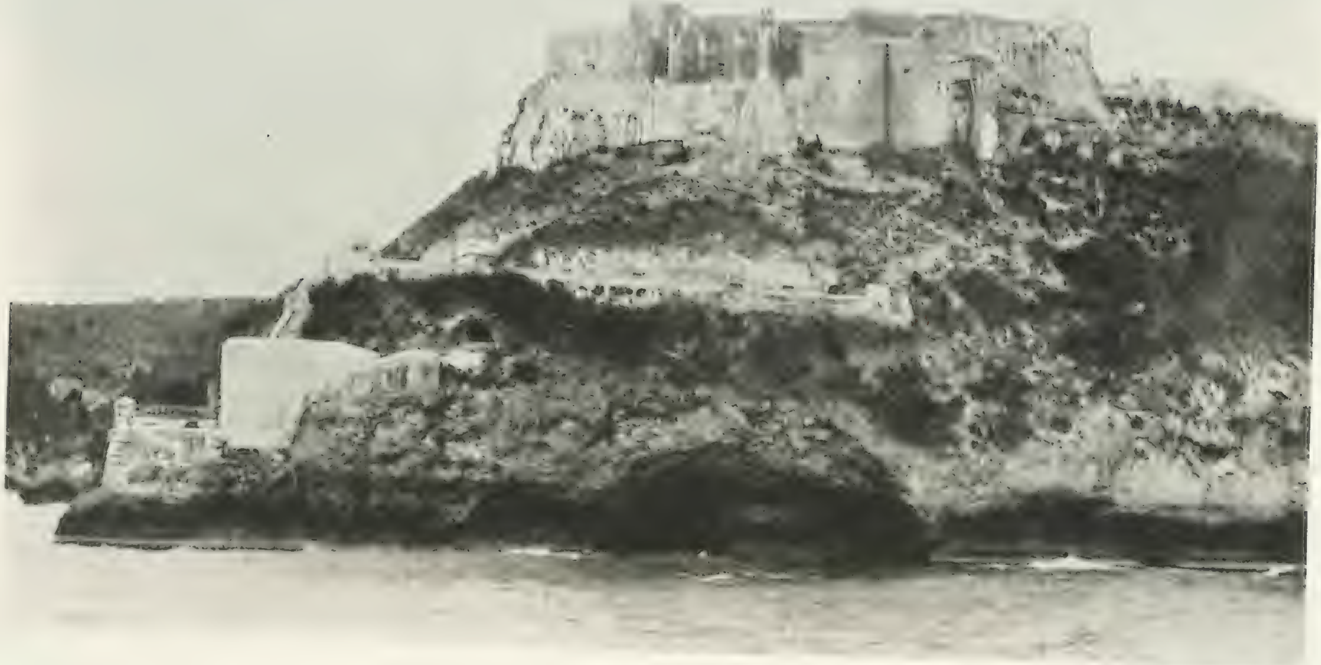
ENTRANCE TO HAVANA HARBOR.



ARTOTYPE. E. BIERSTADT, N. Y.

PATCH OF SOBORUCO, MORRO CASTLE, HAVANA.

PLATE XLVII.



ARTOTYPE, E. BIERSTADT, N. Y

MORRO. ENTRANCE TO SANTIAGO DE CUBA.

Bulletin of the Museum of Comparative Zoölogy
AT HARVARD COLLEGE.
Vol. XXVI. No. 2.

# A VISIT TO THE BERMUDAS IN MARCH, 1894.

By Alexander Agassiz.

With Thirty Plates.

CAMBRIDGE, MASS., U. S. A.:
PRINTED FOR THE MUSEUM.
April, 1895.

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## No. 2. — *A Visit to the Bermudas in March,* 1894. By ALEXANDER AGASSIZ.

### GENERAL DESCRIPTION.

BEFORE completing my article on the Bahamas I was anxious to visit the Bermudas. During my visit I chartered a sea-going tug, and was thus able in a comparatively short time to cover every interesting spot on the shores of the islands and on the inner and outer ledge flats. During the spring of 1894 I spent about a month in their examination,[1] and find that the story of their present condition is practically that of the Bahamas, with the exception that at the Bermudas we have an epitome as it were of the physical changes undergone by the Bahamas. One cannot fail to be struck with the insignificance of the corals as compared with those of Florida, of the Bahamas, and of the Windward Islands. It is true that on the ledge patches inside of the so called "ledge flats" the Gorgonians and Millepores are very flourishing, but the development of the true reef builders, of the massive corals, is insignificant; while the absence of Madrepores is remarkable, and changes the whole aspect of the coral growth.

I shall have little to add to the description of the Bermudas as given by Nelson, Rein, Thomson, Rice, and Heilprin, but I am inclined to take a different view of the part which the corals now growing there have played in the formation of the reef ledge flats. The corals have not added any material part to the reefs; they form only a thin veneer over the disintegrated ledges of æolian rock which constitute the so called reef off the south shore of Bermuda and the ledge flats of the reef ring near the outer edge of the Bermuda Bank. Æolian rock ledges underlie the coral growth not only on the patches off the south shore and on the ledge flats of the outer reef, but they also underlie the so called patches and heads forming the flats which extend on both sides of the main channel and divide the lagoons or interior waters of the bank into irregular sounds, like Murray Anchorage. The passage of the shore æolian rock ledges into the coral patches can easily be traced, off both the north and the south shores, as will be seen later on.

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[1] Notes from the Bermudas. By Alexander Agassiz. From a letter to Professor James D. Dana, dated Bermuda, March 12, 1894. American Journal of Science, 3d ser., Vol. XLVII. No. 282, June, 1894.

I have to thank his Excellency, the Governor of the Bermudas, General Lyon, for permission to make soundings and dredgings among these islands with the view of studying the coral formation. To the Hon. Archibald Alison, Colonial Secretary, I am indebted for assistance in many ways during my visit to the Bermudas, especially in obtaining information from the government officers, and for a fine specimen of floating pumice stranded upon the south shore; and to Captain Carr, R. N., in charge of the Bermuda dockyard, for information regarding Ireland Island and the flats. I have to thank General Russell Hastings and the American Consul, the Hon. Marshall Hanger, for their interest in my explorations, and to Mr. John C. Watlington I am indebted for statistics regarding the temperature of the sea water at different seasons of the year.

The slope of the mountain of which the Bermudas are the summit varies considerably, judging from the three sections given on Plate II. The slope off North Rock (Plate II. Fig. 3) is steeper than the slope off Castle Harbor (Plate II. Fig. 4). Off North Rock the distance from the 100 fathom line to a depth of nearly 1,400 fathoms is about six miles, while off Castle Harbor the 100 fathom line is nearly eight miles from a depth of less than 1,250 fathoms. Off the Argus Bank the 100 fathom line is about ten miles from a 1,370 fathom sounding (Plate II. Figs. 1, 2). These sections show the slope of the island to be steeper off the north face than on the south side of the island.

On the southwest face off Long Bar 1,250 fathoms is found at a distance of five miles from the 100 fathom line, and the 1,000 fathom line is only two miles from the 100 fathom line. Northeast from the East Ledge Flats 1,260 fathoms is found at a distance of five and a half miles from the 100 fathom line. South-southeast from the Southwest Breaker 960 fathoms is found two and a half miles from the 100 fathom line.

The distance of the 100 fathom line from the sea edge of the ledge flats varies but little, though it is true that off the south shore it is nearer as a whole, and it comes to within one mile and a quarter of the shore off Castle Harbor, and on the north side it is as much as three and a half miles from the North Ledge Flats, and east off Mills Breaker it is nearly five miles (Plate I.).

The Bermudas (Plate I.) form a hook-shaped line of islands, the main island running northeast from Gibbs Hill to Castle Harbor, which is bounded on the north by a chain of islands of which St. David is the most prominent, and on the east by a chain of smaller islands, the continuation of the spit east of Tuckerstown, which is the easternmost point of the main island. Outside of Castle Harbor on the north extends a chain of islands which bound St. George Harbor, the largest of which is St. George Island. Endless islets and rocks flank the south shore from Tuckerstown to Church Bay, where the main island makes a sweep to the southwest as far as Wreck Hill. It is separated by a narrow channel from Somerset Island, to the northward.

From Somerset Narrows a chain of small islands extends to the northeast, on the last of which is built the dockyard. The north shore of the main island is flanked by numerous islands, which form Hamilton Harbor, Port Royal Bay, Great Sound, and the connecting waters to the westward of Spanish Point (Plate III.). At the eastern end of the main island a narrow channel opens into Little or Harrington Sound, which covers the greater part of that end of the island. The position of the former Bermudian land is indicated by isolated rocks, like North Rock (Plate VIII.), the Pilchard Dicks, the Southwest Breaker, the South Reef, the Mills and Northeast Breakers, and others rising above the general level of the broad belt of ledge flats which completely surround the summit of the Bermuda mountain. These flats leave only here and there a narrow passage into the interior sounds, bounded by the many belts of flats crossing the inner waters. The principal passages are the Narrows, or Ship Channel, Hog Fish Cut, Chub Cut, North Rock, and Mills Breaker channels, in addition to a few insignificant boat passages. The Narrows is really the only channel navigable for heavy draught vessels.

The Lagoon, lying to the northward and northwestward of the islands, is bounded by the curve of the outer ledge flats. They are submerged at low water, except at a few points such as the North Rock, Mills Breaker, Southwest Breaker, and others marked on the chart (Plate I.). The depth of the Lagoon is in general from seven to nine fathoms, though a few of the deeper points are twelve or thirteen fathoms. Between the outer ledge flats and the islands are found the many secondary flats, called Elies Flat, Cowground Flat, Brackish Pond Flats, Green Flats, Bailey Bay Flats, Three Hill Shoals, and the like, which consist of endless patches of Millepores and Gorgonians, reaching many of them to within a few inches of the surface. The Gorgonians and Algæ which cover the patches have grown upon the remnants of ledges of the proto-Bermudian land that attest to its former existence at so many points, not only of the outer reef ledges, but on the flats intervening between them and the Lagoon (Plate XVIII.). Between these patches separated by deep water, and plainly seen by its discoloration, it is comparatively easy to find one's way when the water on the banks is not rendered milky by winds stirring up the bottom.

Lagoons similar to those between the reef and the islands are Great Sound, Port Royal Bay, Hamilton Harbor, Harrington or Little Sound, St. George Harbor, and Castle Harbor. These sounds, as the inner lagoons are called, differ from similar sinks in the outer lagoon by being bounded in part or wholly by land, while the sounds in the outer lagoon are more or less indistinctly limited by flats formed of "coral head" patches (Plate I.).

Harrington Sound is connected with the outer lagoon by a narrow channel, the Flats Inlet; it is, in fact, in the condition of many of the smaller bays on the south shore, where the sea has only comparatively lately encroached upon the interior sinks. I refer to such bays as Sinky, Hungry (Plate XV.), Devon, and the like. In the case of Little Sound, the opening at Flats Inlet broke through the ridge separating the outer lagoon from an extensive sink, the smaller elevations of which have entirely disappeared, with the exception of a few islands and shoal patches. Castle Harbor and St. George Harbor were probably similar sinks, the outlines of which are still indicated by the line of islands protecting in part the southern face of Castle Harbor, while the outline of the narrow sink forming St. George Harbor is shown by the islands which separate it from the Narrows, and by St. David and Long Bird Islands, which are the remnants of the ridge dividing St. George from Castle Harbor. But both these ridges are now broken through, so that Castle Harbor connects with St. George Harbor and on the north with the lagoon forming Murray Anchorage.

The æolian hills extending eastward from the northern entrance to St. George Harbor are most characteristic, and the saddles separating them are of varied elevations, and show how readily the sea could, after a very limited subsidence, find its way into sounds like Castle and St. George Harbors at a time when they probably appeared much like the nearly closed Harrington Sound (Plate V.).

As Professor Heilprin has stated, it is merely a question of time when Harrington Sound will be more of an open bay than of a land-locked lagoon, presenting in time the appearance of Castle Harbor, and finally perhaps that of Great Sound.

An examination of the chart (Plate I.) reveals faintly the position of similar lagoons, the limiting land of which has been entirely washed away. Such are the three small lagoons situated in the flats to the south of East Ledge and to the west of Mills Breaker, showing channels leading into them from the bank similar to the Narrows which lead from the edge of the bank to the lagoon forming Murray Anchorage. A number of such open lagoons facing south are found extending into the inner edge of the reef flat, to the eastward and westward, directly south of North Rock, as far west as the Eastern Blue Cut. On the outer face of the reef south of Western Blue Cut, at the Chub Cut, the Chub Heads, and between High Point and the Chaddock Bar, a number of such open lagoons can be traced. Long Bar is a flat ledge which once may have formed the barrier of a narrow lagoon open at its two extremities.

The so called reef off the south shore I look upon as a series of ledges, the remnants of the cliffs of the shore when it formerly extended to the present position (Plates XXI., XXIII.) of the reef. One cannot fail to read the mode of formation of this reef on seeing the work of destruction which has been and is still going on all along that coast (Plate XIX.). The shore of the island is gradually being eaten away at all the low points leading either into sinks like those of Sinky or of Hungry Bay, or into more elongated sinks like those which will be formed when the ponds lying close to the shore to the westward of Tuckerstown are invaded by the sea (Plate XIV.). The next process is the formation of a line of islands, such as still protect Castle Harbor and St. George Harbor on their sea face (Plate XXI.), or, as is well seen at Sinky Bay, where the line of rocks to the north and south of the opening is still connected with the shore line by a beach or neck, but which will soon disappear and change that bay and the one to the north of it into an extension of Whale Bay. On the sea face of that part of the coast extends a long line of isolated rocks, islets, rocky patches, and sunken ledges, which plainly tell of their former connection in a continuous ridge. Parts of these ledges are worn to the water's edge, forming flat ledges or mushroom-shaped rocks overgrown with Algæ and Serpulæ, and likewise the Serpulæ atolls (Plates XXIV.–XXVI.) and boilers of the shore line, similar to those which form the outer reef, and are separated by a belt of water varying from one and a half to four fathoms close to the lee side of the reef. At some points of the shore it is difficult to separate the line of the outer reef, and of its ledges extending towards the shore, from the ledges which form the Serpulæ reefs of the shore line itself (Plate XXVI.).

The amount of material which is kept in constant movement by the action of the sea within the outer line of ledges is very great, and is constantly increased by the additional material derived from the breaking up of the outer ledges by seas of unusual violence. The outer as well as the inner ledges become disconnected; passages between them are opened with four fathoms of water, or even more. The outer slope of the ledges is greater than the inner slope, the depth of water increasing in some places rapidly from the ledges which are awash at low water to six or seven fathoms, or even up to twelve off Castle Harbor. From that depth, judging from the soundings on the hydrographic charts, the slope is quite gradual, twelve fathoms usually being found at a distance of nearly a mile from the outer ledges; off the outer side of the western reefs the slope is somewhat steeper, and off the northeastern face of the reefs from the Western Blue Cut to North Rock the slope is slightly flatter.

Two small disconnected banks exist to the southwest of the Bermudas with a least depth, the one of twenty-one, the other of twenty-four fathoms (Plate II.). A depth of over 1,000 fathoms has been sounded between the main Bank and the Challenger Bank, while one of 580 fathoms has been obtained in the channel between it and the Argus Bank. The bottom in these is stated to be coral sand, and these banks may, like the Bermuda Bank itself, be the summits of volcanic peaks which have risen from a greatest depth of more than 2,000 fathoms at a distance of about nine miles from the 100 fathom line.

The Bermudas present quite a different physiognomy from that of the Bahamas. The hills are more diversified in shape, many of them quite conical, surrounding lowlands or sinks of considerable extent and of great variety of shape. Along the northern shore of St. George Island, except towards the east end, the hills are undermined as they reach the water line, forming low cliffs in marked contrast to those of the south shore, or on the waters of Harrington Sound and St. George Harbor and the northern coast of Castle Harbor, where in certain places the water has undermined the cliffs, and from them have dropped off huge masses leaving vertical sides of considerable height, from fifty to seventy feet. On the north shore only a few short stretches of the coast are occupied by sand beaches. Shelly Beach is the only one of considerable length. On the south shore we find sand dunes and many long stretches of broad sand beaches (Plate XI.) which supply the material for the dunes that are still in some places forcing their way inland over the ancient dunes, as at Tuckerstown, Elbow Beach (Plate XII.), and Whale Beach.

Professor Heilprin is of the opinion that perhaps the natural arches at Tuckerstown were formed at a time when the relations of land and water were different from what they are now; though it is difficult to ascertain precisely what his views are. Here, as at the Bahamas, many sinks occur in which, owing to the porosity of the rock, but little water can remain; if the sinks are at some height above the sea level, this undoubtedly permeates the interior of the island, and whenever the sinks reach below the level of the sea they are filled with brackish water. There is very little difference in the appearance of the rocks composing the islands. We have by no means the variety in the appearance of the æolian rocks met with in different islands of the Bahamas.

Solution has undoubtedly played some part in producing many of the fantastic spires of æolian rocks one meets in the Bahamas and Bermudas. The undermining of the shore cliffs, the mushroom shape of many of the isolated rocks and shore ledges, both above and below low-water mark, is in part due to the solvent action of sea water. This is especially well seen in the Bahamas on every island or islet at many of the channels leading from the sea face on to the bank.[1] On the Bermudas this is perhaps best seen in the formation of the pinnacles in the comparatively quiet waters of Mullet Bay and of Castle Harbor, and in the undermining of all the shore cliffs and the cavernous and honeycombed condition of the older ledge patches between the islands and the reef flats and those of the ledge flats themselves. Close to the Causeway at the northwest part of Castle Harbor there is quite a patch of low pinnacles from two to two and a half feet in height, which seem to show an active solvent action by the sea.

But the solvent action of the salt water cannot be compared in efficiency with the destructive mechanical action of the sea; the latter has to a great extent been arrested by the covering coat of Gorgonians, Millepores, Algæ, and Corallines, as well as of the more massive corals found thriving upon the heads, patches, ledges, and ledge flats of the inner and outer waters of the Bermudas. But these heads, ledges, etc. do not, as has been stated by former observers, owe their existence and their gradual increase to the corals, as they consist of æolian rock with only a protecting veneer of corals over their surface, constituting a coral growth, and not a coral reef.

In the region of the Everglades of Florida,[2] the process of solution of the limestone rocks has been an important factor in shaping the general plane of the region. No one can find their way any distance into the Everglades without being struck with the deeply corroded and honeycombed aspect of the rocks, and the numerous sink-holes, due to the effect of the rain water saturated with acids derived from the decaying vegetable matter.

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[1] See A. Agassiz, The Bahamas, Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, 1894, p. 49.

[2] The Topography of Florida, by N. S. Shaler, Bull. Mus. Comp. Zoöl., Vol. XVI.

Heilprin has well shown that the lagoons and sounds of the Bermudas are not kept open through solution, and do not owe their origin or increase to that cause.[1] But I think he has underestimated the effect of solution on the cliffs and ledges where exposed to the action of the sea. The solution effected by the percolation of fresh water is clearly seen in the sinks,[2] pot-holes, and caverns opening out on all the cliff exposures and in many of the cuts in the honeycombed surfaces of the æolian rocks wherever laid bare. There is hardly a vertical wall or cut for a road which does not show some trace of the solvent action of water percolating through the æolian beds and covering patches of the edges of the strata with a stalagmitic coating, so as to obliterate their dividing lines or form small stalactites from bed to bed.

A comparison of the base of the sea faces of the cliff ledges with the sides of the mushroom-shaped rocks below low-water mark will clearly indicate the different kind of work accomplished by solution by sea water acting upon the more or less submerged vertical faces, and that exhibited by the action of fresh water some yards above the high-water mark. The effect of the solvent action of the sea water is readily traced above the high-water mark as far as the waves or spray can reach, and the encroachment of the sea water upon the area partly honeycombed by fresh water is most instructive (Plates XXVIII., XXX.). Above high-water mark the area exposed to this action is very considerable, and by the solvent effects of sea water upon the limestone area exposed be-

No. 7, 1890, p. 145. See also Murray and Irvine on Coral Reefs and other Carbonate of Lime Formations in Modern Seas, Proc. R. Geog. Soc. Edinb., 1889–90, Vol. XVII. p. 79.

[1] Bermudas, p. 44.

[2] Professor Dolley accounts for the formation of banana holes by the action of decaying vegetation collected in the holes, kept moist by the action of rains undergoing fermentative changes by the product of which the soft calcareous rock is dissolved and leaches away. This process undoubtedly acts as suggested by Professor Dolley, but only to a limited extent, as the most active honeycombing takes place on the surface of barren islands, where the vegetation has long ago disappeared, but where the surface is exposed to the combined action of rain and of salt water spray, as at Glass Window, Great Isaac, and other places in the Bahamas. See A. Agassiz, Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, 1894, pp. 30, 60.

tween high and low water mark a very considerable amount of lime must be removed, probably as much as the sea water will hold in a saturated solution. Additional lime may also be taken in solution, while innumerable minute particles are held in suspension during rough weather. At the time of our visit, the wind having blown for two days quite persistently from the northwest, the whole bank was fairly milky white in a belt extending from five hundred to seven hundred feet from the north shore. The isolated patches on the edges of the greater ledge flats were also indicated by the white waters surrounding them; while the deeper parts of the outer sounds were indistinctly indicated by a more bluish tint of the water.

The so called patches and reefs appear like diminutive vertical cliffs, or parts of cliffs, which once were broken off from the larger shore line cliffs then existing. Of course their faces and surface have been to a certain extent modified by the growth of corals upon them, but that only to a very limited degree. The coral patches are built up over a substratum of æolian rocks.

The islands as seen from the north present in general the features of the æolian hills of the Bahamas, although they have a more varied outline (Plate IV.). There are more conical hills, and there are not as many of the distinctive lines of ranges of æolian hills trending in one direction. Many of the islands in Hamilton Harbor are quite bare, their surface indurated by the action of rain and more or less honeycombed, as is the case in the majority of the Bahamas. The absence of vegetation is also marked over a great part of the western extremity of Spanish Point. There is a very fine æolian cliff on the bay at the foot of Admiralty House (Plate XVI.).

On the north shore the trees and shrubs of the main island do not run close to the water's edge. From the somewhat scantier groves of juniper crowning the summits of the successive æolian hills run broad grassy undulating slopes, terminating in the comparatively low vertical cliffs which characterize the north shore of the principal island. All the way from Spanish Point to Harrington Sound there is an unbroken line of these low vertical cliffs (Plate XXVIII.), with the exception of a few insignificant sandy beaches breaking in occasionally, the only prominent exception being Shelly Beach. The islands of St. George and St. David are comparatively bare (Plate V.), and the general aspect of the country at the eastern extremity of Bermuda reminds one of the aspect of the long lines of barren islands so common in the Bahamas. On the southern and western slopes of St. David junipers grow more abundantly, and the narrow band separating Castle Harbor from Harrington Sound is comparatively well wooded (Plate VI.). Though there has been over that district a greater denudation, judging from the general appearance of the outcrops of isolated patches of weathered æolian rocks, which form here and there low vertical cliffs.

The hills to the eastward of the flats extending on the north shore to St. George Island and the islands protecting the entrance of the harbor are comparatively bare of vegetation. The few stunted cedars and other bushes growing on the north side of that part of the Bermudas are mainly limited to the southern slopes. In fact, all the eastern part of the Bermudas, including the territory around Harrington Sound, shows far more than the central part of the principal island the effect of denudation which has taken place both there and in the western district of the group. The æolian rocks crop out in all directions, greatly weathered, and are near the surface changed to hard ringing limestone.

Toward the summits of the hills and in the saddles passing into the interior of the main island the cedars are more abundant, and in the lower and better watered valleys palmettos grow in small groves, forming the same contrast with the Bermuda cedars which they do in similar localities with the pines in the Bahamas. In all directions the wild verbena is to be found, either as the only growth in the more barren districts, or encroaching to a great extent on the open spaces of the wooded parts of the islands. In the valleys and lowlands of the islands, the soil is sometimes of considerable thickness. This is especially the case in the series of longitudinal sinks parallel with the south shore, which extend from Hungry Bay through the greater part of Devon.

At the western as at the eastern extremity of the islands we find a similar diminution in the vegetation. The southwest end of Somerset Island is bare, and the surface greatly worn. On the rest of the island there are fewer junipers than on the main island, and they are smaller and more scattered, as they are on the east end of the main island all the way from Wreck Point to High Point.

The difference in the aspect of the Bermudas and Bahamas is perhaps due to the prevalence of the trade winds in the latter, where they have had the tendency to build sand dunes bearing in one direction, their sea slope being abrupt, while the bank slope is more gentle, thus forming long lines of dunes lapping and running in one direction. This leaves long, narrow valleys between the ranges of dunes, and, as is well seen at Nassau and Andros, produces a greater monotony in the outlines of the islands as compared with the varied landscape of Bermuda. These valleys often become sinks (Plate XIV.) or elongated pools, and when broken into by the sea soon leave a line of cays parallel to the main shore. The winds are more variable at Bermuda, the islands being several degrees north of the limits of the trades, while the Bahamas are on their northern edge.

The general aspect of the Bermuda vegetation is characterized by the presence of the Bermuda juniper, which has assumed in these islands the prominence which the pine has taken on the Little Bahama Bank, on Andros, and on New Providence. Comparatively few of the plants so characteristic of the shores of the most barren of the Bahamas are met with near the shore line.

The Algæ and Corallines which I collected at the Bermudas were kindly examined for me by Professor Farlow. Off the sand beaches of the south shore on the bottom of the interior sounds the calcareous Algæ consisted mainly of species of Penicillus, of Bostricha, of Udotea, and of Halimeda, identical with West Indian types. On the rims of the serpuline atolls (Plates XXIV.–XXVI.) were collected species of Turbinaria, Galaxaura, Blodgettia, Dasyclades, Codium, Laurencia, Dyctyota, Eucheuma, Sargassum, Zonaria, Caulerpa, and Janca, all of which also occur on the outer ledge of flats and inner patches.

Professor Moseley collected a number of marine plants at the Bermudas which have been described in the Journal of the Linnæan Society, and his collections of the flowering plants formed the basis of the extended Report on the Botany of the Bermudas by Hemsley,[1] where a full account of the earlier sketches of the flora of these islands will be found. Professor Charles S. Dolley has also given an account of the Botany of the Bahamas.[2]

The principal accounts we have of the geology of the Bermudas are those of Captain Nelson.[3] The geology in Jones's "Naturalist in the Bermudas" (1859) is taken mainly from Nelson's Report. Rein gave a most interesting sketch of the geology of the islands in the Bericht. ü. d. Senckenbergische Naturf. Gesellschaft for 1870, page 140; he was followed by Sir Wyville Thomson,[4] who spent a short time in the Bermudas, and next in order came the visits of Rice,[5] of Fewkes,[6] and of Heilprin.[7] Darwin is of the opinion that the Bermudas "have a close general resemblance to an atoll," although they differ from one in several respects which he enumerates. Dana and Sir Wyville Thomson regard the Bermudas as part of an atoll. Thomson thought the islands were formed "by the raising of the weather edge of the reef above the level of the sea."[1] Professor Rice also considered it an atoll, but he was careful to distinguish between the present outlines and those which belonged to the original atoll.

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[1] Voyage of H. M. S. "Challenger," Botany, Part I., W. H. Hemsley, 1884.

[2] Proc. Phila. Acad. Nat. Sciences, 1889, p. 130.

[3] Trans. Geol. Soc. of London, V. 103, 1837.

[4] The Atlantic, I. 289, 1877.

[5] Bull. U. S. Nat. Museum, No. 25, 1884.

[6] Proc. Bost. Soc. Nat. Hist., 1888.

[7] The Bermuda Islands, 1889.

Professor Rice suggests the following heads as his explanation of the geological history of the Bermudas: —

"1. A subsidence in which the original nucleus of the island disappeared beneath the sea, the characteristic atoll form was produced, and the now elevated beach rock was deposited.

"2. An elevation in which the great lagoon and the various minor lagoons were converted into dry land, and the vast accumulations of wind-blown sand were formed which now constitute the most striking peculiarity of the islands.

"3. A subsidence in which the soft drift rock around the shores suffered extensive marine erosion and the shore platform and cliffs already described were formed."

As regards 1. This is the natural explanation which would be given by the Darwinian theory of the formation of coral reefs to account both for the disappearance of the original nucleus and for the formation of an atoll. To those who do not accept the theory the disappearance of the nucleus is of course explained by subsidence also, but by the subsidence which followed the formation of the dunes from an extensive ring-shaped coral sand beach of which the material was derived from a reef growing upon the upper plateau of the Bermudian mountain, from a depth of less than twenty fathoms.

2. Whenever the accumulations from the reef were sufficient to build up a beach reaching the surface, all the conditions necessary for the formation of sand dunes existed, and we need not call upon either a subsidence or an elevation to account for the existing condition of the Bermudas.

3. The subsidence which I imagine to have taken place after the building of the dunes from the broad beach surrounding the original nucleus — now sunk or disintegrated — is, it seems to me, quite sufficient to explain the existing condition of the dunes and cliffs of the Bermudas, if the interpretation I have given of the base rock is the correct one.

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[1] The Atlantic, I. 302.

I shall have occasion to refer to the views of Heilprin in the course of the following pages. Regarding the statement he makes on the nature of the Dolomitic reefs of the Tyrol, I would refer the reader to my Report on the Bahamas, page 179, where I have given an abstract of the views of the latest researches on the nature of the dolomitic reefs, views which are diametrically opposed to those advocated by him.

Heilprin says: "If it ever existed (the atoll condition), it has been completely masked by overgrowth; . . . the facts, such as they are, show with sufficient clearness that the present islands and reefs have little or nothing in common, beyond occupying position, with a preexistent ring."[1] Yet it is on observations gathered in a district thus characterized by him that Heilprin bases his assent to the Darwinian theory of coral reefs, and he dissents from those who hold opposite views with a vehemence which might be excused in one having an extended acquaintance with coral reefs.

## ÆOLIAN HILLS AND DUNES.

Captain Nelson was the first to call attention to the æolian character of the rocks of the Bahamas and Bermudas. This character *saute aux yeux* in every direction. In the Bahamas the vertical cliffs of the weather side of the islands show this to perfection, and here and there a quarry or a cut leaves no doubt that the substructure as well as the superstructure of the island is all of the same character. On the Bermudas one comes upon quarries of all sizes at all points, close to the sea level or near the highest summits, and at all possible intermediate elevations. The rock everywhere presents the same structure. There are also endless rock cuts for the passage of roads (Plate IX.), giving excellent exposures of the æolian strata twisted and turned in every possible irregular manner according to the direction of the then prevailing winds, or we may come across a patch exposed in a cliff or in a deep cut where the strata run parallel for quite a distance. As in the Bahamas, the surface of these æolian rocks has become indurated by the percolation of fresh water through its mass, and has formed here and there the thin ringing coating so common all over those islands, where the surface is not so well protected by vegetation as it is in the Bermudas. Throughout the islands we come upon evidence of the extensive denudation and erosion which have affected the æolian rocks of the islands and worn them into the varied forms they have assumed, either along the more exposed shores or in the sheltered bays and inlets and sounds. Some of the æolian pinnacles off Castle Harbor have assumed the most fantastic shapes, due to the combined action of the weather and of the solvent and wearing action of the sea and rain.

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[1] Bermuda Islands, p. 40.

Sir Wyville Thomson [1] has also given an excellent account of the general characteristics of the æolian formation. Heilprin has called attention to the comparatively insignificant part which corals play in the supply of the material which has gone to form the æolian hills of the Bermudas, and which, as in the Bahamas, is made up of many other organisms. Among them Nullipores, Corallines, broken shells, and Millepores take a most important place. In some localities, where the æolian rocks have not become well indurated, it is not infrequent to have secondary dunes formed from the sand derived from the breaking down of one of the softer cliffs, the dunes covering to a certain extent the older æolian hills, much as the æolian sand of the south coast climbs over the faces of the older hills.

The fine coral sand, which is so often spoken of as washed up on the shores by the sea,[2] is not, strictly speaking, coral sand, but is primarily composed of fine sand derived from decomposed æolian rock. This material is derived from the disintegration of the shore cliff ledges, and from that pounded off by the sea from the outer reef ledges, together with the broken shells of the mollusks living upon the flats and the small amount of material supplied by the breaking up of the massive corals and Gorgonians forming the coral growth upon the ledges, the ledges themselves consisting of æolian rock covered by Algæ, Corallines, Serpulæ, and Millepores. On the south shore this fine sand is blown far inland, forming dunes which cover extensive tracts;[3] at Middleton Bay beach they run up over the surfaces of the older solidified dunes, and reach to a height of over one hundred feet from high-water mark, encroaching upon the vegetation near the lee summit of the saddle through which they are blown. A row of small dunes has formed on the edge of the beach south of Whale Bay; a larger dune has also been piled up inland within the line of the beach dunes, extending over an older but smaller solidified dune (æolian hill); just as the beach sands at Elbow Beach (Plates XI., XII.) have run to a height of more than one hundred feet, although here the sand dunes do not extend as far inland.

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[1] Voyage of H. M. S. "Challenger," The Atlantic, I. 310.

[2] Ibid., I. 307.

[3] See the excellent accounts of the dunes by Thomson, Ibid., 312.

It is probable that the other non-calcareous rocks and minerals which have occasionally been found may have been brought here by floating trunks and roots of trees, as is the case in many of the oceanic islands. We should, however, not forget the possibility of their being the fragments of the volcanic summit around which the proto-Bermudian reef was first formed, a summit which has completely disappeared, either owing to subsidence or to disintegration, or to both combined. There exists in the collection in the Government Building a piece of fine-grained æolian rock of a reddish tint from the north shore near Warwick Road, in which is embedded an angular fragment of basalt, or some eruptive rock.

For a coral island the elevation of the Bermudas is very considerable. The highest points are Sears Hill, 260 feet, Gibbs Hill, 240 feet, and Prospect Hill, 222 feet; a number of points reach an elevation of nearly 150 feet. On the Bahamas, with the exception of the highest points of Cat Island, which are said to reach 400 feet, the greater number of the æolian hills do not rise to more than from 60 to 100 feet, very many of the islands attaining a height of not more than from 20 to 40 feet, and only a few summits reaching over 200 feet. But it should be remembered that the heights named are not due to the elevation of coral reef rock, but to the height attained by the æolian hills which constitute the dry land of the two groups.

The Bermudas and Bahamas[1] offer an example of the thickness that a recent limestone deposit may attain during a period of rest. Assuming for the Bermudas a probable subsidence of 70 feet and a greatest elevation of 260 feet, we get an æolian coral limestone of 330 feet in thickness, the material of which has all come from a reef which itself was probably not thicker than 120 feet, or a total thickness of 450 feet. When we remember how readily these coral limestones are changed into hard ringing rocks, we introduce a new element into the discussion of the mode of formation of huge masses of limestone, especially in the region of the trade winds.

The beach rock and the so called base rock which have been observed at the Bermudas belong, I believe, to two different types. The former, the beach rock, consisting of coral or other sand, is deposited in strata dipping to the sea at a slight inclination, and is characteristic of all coral reef districts where sand is accumulated along a shelving line of coast. This frequently becomes hardened and changed to a ringing limestone, and is composed usually of rather coarse particles, but not necessarily so. The base rock, considered by some of the writers on the Bermudas to underlie the æolian hills, I look upon as the modified part of the lower portion of the æolian strata changed into a hard ringing limestone in which all traces of stratification have often disappeared (Plates XVI.–XVIII.).

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[1] A. Agassiz, Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, p. 183.

Heilprin argues that the beach rock has been elevated and is still found at an elevation of 12 to 16 feet; that it "antedates the last subsidence, . . . is at least as ancient as the lagoons and sounds, and probably much more ancient. Indeed, there is nothing that could lead one to suppose that it is not the original rock which was formed when the island first came to the surface. Although now exposed on the sea border, it is really an interior rock, as is proved by the broad band of land which must have been removed from the seaward side of the existing cliffs."[1] But this neither indicates elevation, nor that it is an original beach rock, since at the western extremity of the Bermudas, at Ireland Island, it is underlaid by true æolian beds fifty feet below low-water mark. It does not seem to me that beach rock is found at any greater elevation than that at which it could have been thrown up (and subsequently cemented) during a hurricane or violent gale.

The shore platform of which Professor Rice speaks appears to consist only of modified æolian strata, changed into hard ringing rock by the action of the sea, and of a shore platform eroded to ledges, as he himself describes them. He well says, when speaking of the relation between drift and beach rock on the south shore, "If we conceive the seaward face of the dune to be restored, it would certainly in some localities extend beyond the narrow shore platform into the area now covered by the sea."

Can we not find a simpler explanation of the formation of the Bermudas than the one suggested by Rice? Instead of a subsidence during which the nucleus disappears, followed by an elevation during which the æolian hills were formed, and then by a subsidence during which the present soft drift rock was eroded, as is suggested by Rice, we need only a single subsidence to explain all the phenomena, if, as I have suggested, base rock is only modified æolian rock, and beach rock has been forming continuously, and the æolian hills were formed at the time when the atoll was one gigantic annular beach constantly receiving fresh material from the outlying reef. This primordial reef has disappeared, and its remnants exist perhaps at depths of from twenty fathoms or more near the edge of the bank.

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[1] Bermudas, p. 43.

Darwin's suggestion that the fringing reef on the south side of the Bermudas is evidence of recent elevation, does not, in view of the fact that the reef is made up of æolian ledges, need any discussion. Nor is the reason given by Dana regarding the cause of the great difference in the amount of dry land on the north and south side of the atoll a satisfactory one, if the ledges are æolian ledges, which were the first to disappear after subsidence began. I am inclined to look upon the present state of things as due to the former existence of lower æolian hills on the northern edge of the islands;[1] but his views would apply for proto-Bermudian times.

My observations lead me to look upon the beach rock of the Bermudas as consisting mainly of the larger and heavier æolian materials, which either have not been carried so far or blown to so great a height as the lighter æolian sand. The effect of the intermittent submersion of the æolian rocks exposed at low-water mark seems to be to cement the particles on the exposed lines of the knife-edged strata by a process very similar to that going on in all the deep road cuts on the islands. By it all traces of stratification are gradually lost, and an upper crust running over the exposed surface is formed irrespective of the æolian layers. Thus a belt of comparatively hard rock is formed, covered with a crust ringing to the hammer, which at first sight appears to be unconformable with the æolian strata. A closer examination invariably reveals at no great distance traces of the continuation of the æolian stratification, which continue plainly visible to high-water mark, to points below it, and at intermediate heights. Where the sea breaks violently against a vertical cliff, this cementing effect, accompanied by the disappearance of the evidence of stratification, can be traced in some cases well above high-water mark, where it gradually passes into the region honeycombed and pitted by the action of the rains. Such parts of the rocks cannot be distinguished from the base rock, and they have all its characteristics except that the cementation is not quite so complete (Plates XV.–XVII. and XXVIII.).

Here and there along the beaches beach rock is forming, as in some parts of Great Turtle Bay, of the shore south of Whale Bay, in Whale Bay itself, and between short projecting headlands where the *débris* from the outer and inner ledges accumulates in greater quantity. This beach rock is generally readily recognized as such. It is formed in fairly thick layers, from two to six inches, and always dips toward the sea at a very moderate angle, and has nothing in common with the æolian strata against which it abuts. Parts of it may be ground up again by a storm should the calm between heavy surfs not continue sufficiently long for it thoroughly to consolidate.

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[1] It seems somewhat hazardous to attempt, as Rice has done, to correlate the movements of elevation and subsidence of what probably is a volcanic cone — of which he has, as he thinks, found evidence — with those of the American continent. (Bull. Nat. Mus., No. 25, p. 18.)

All along the south shore one can find patches of beach rock dipping, as observed by Professor Rice, to the sea at a slight angle, — the modern beach rock of to-day, formed from the remodelling of the material thrown up from the outer ledges. This beach rock is formed similarly to that of the Florida Reef, where it plays so important a part in its economy, while at the Bermudas it is of comparative insignificance. It is often difficult to separate the beach rock from the base rock, but if, as I believe, what is called "base rock" is only modified æolian rock, the latter has not the importance attributed to it by Professors Rice and Heilprin. On White Cliff Bay there are some æolian cliffs dipping at a sharp angle into the sea, showing remarkably well the transformation of the thin æolian layers into massive compact beds of base rock, in which the dip of the strata can scarcely be detected, obliterated as it has been by the cementing and solvent action of the sea water acting upon them.

At Hungry Bay, Middleton Bay, and many points on the south shore, and on the north shore at Ireland Island, and on the north shore of St. George, there are numerous localities where it is possible to observe the transition of the inclined or horizontal æolian strata above high-water mark to the solid ringing limestone characteristic of the "base rock." On the shore of Godet Deep to the west of Heron Bay, at the foot of Gibbs Hill, the "base rock," can be seen passing gradually from the æolian beds into the solidified ringing limestone characteristic of the intratidal limits. The action of the sea cements the strata together, so that all trace of their æolian structure is lost. In many cases, however, we can trace the continuation of the æolian stratification indistinctly, so that I am inclined to consider what is termed "base rock" as due merely to such cementing action of the sea; the more so, as similar phenomena are clearly observable all along the Cuban coast on the shore edge of the elevated reefs between low and high water mark, where there is no question of an underlying base rock.

Professors Rice and Heilprin both speak of the "base rock" as distinguishing the old beach formation, and as indicating the position of the former sea border. It seems to me that this basal rock is æolian rock which has become excessively indurated by the action of the sea water upon the lower part of the æolian strata, and from being friable and crumbling, as they are above the reach of the sea, have been changed into a solid compact limestone, which rings under the hammer and can be chipped off in sharp-edged flakes. This is similar to the hard ringing beach rock now forming, and does not, it seems to me, indicate the position of the former sea border. Almost anywhere on the south shore one finds the base of æolian cliffs consisting of strata dipping inward, changed as high up as the sea can reach, into this hard compact ringing limestone. A similar "base rock" fringes all the Bahama Islands; inland at Nassau, as at the Bermudas, a few steps from the shore inside of the "base rock," the æolian structure is clearly defined in quarries and wells extending below the water line, but the sea, acting merely by percolation, has not changed their thin edges and cemented them as it has on the sea face of the shores where the strata are fully exposed to the action of the sea, and are in addition exposed for a longer or shorter time to the atmosphere during low-water periods or during the intervals between consecutive breakers.

Rice says of the locally called base rock, "that it does not uniformly underlie the softer rocks, nor is there any evidence that it is older than they."[1] A part of the confusion between base and beach rock seems to me to have arisen from considering the ledges of æolian rock as reef rock, and from the fact that there are a few localities on the south shore where beach rock is actually forming from æolian rock sand, derived from ledges in deeper water, mixed with broken shells and fragments of corals and Millepores, all of which particles are cemented by the deposition of lime held in solution in the water percolating through its masses.

Rice further says, "That there can be no absolute distinction between beach rock and drift rock will be manifest from the consideration that the two formations are in their origin strictly continuous." Yes, but their origin is not the same; the beach rock of to-day is formed in great part of the æolian rock of former days. I would go one step further in believing that the base rock is by no means usually beach rock, but that beach rock is a very local phenomenon, and is younger than the æolian rock, and belongs to the present epoch, and has been forming at different levels, as it is forming to-day in favorable localities, from the time the islands began to subside, as well as before that time. I am at a loss to know what Rice and Nelson can mean by reef rock, unless it be the thin crust of coral growth upon the ledges. I am inclined to adopt

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[1] Bull. Nat. Mus., No. 25, p. 9.

Thomson's view,[1] that the Bermuda limestone is entirely æolian, and that the base rock does not underlie the softer æolian rock,[2] but to modify it by the above statement regarding the formation of base rock and of beach rock as now forming mainly from the remodelling of older material.

Rice accepts the Agers Island strata as beach rock, as well as the stratum at the south end of Ireland, a statement from which I must most emphatically differ. These beds contain marine shells in æolian strata. The base rock of the islands of Hamilton Harbor appears, as far as I have observed it, to be due to the induration of the lower strata of the æolian rock exposed to the action of the sea. There are but few islands in Hamilton Harbor of which the æolian strata do not dip at a considerable angle towards the low-water mark line into the sea. It is true that in some cases there are also æolian rock strata parallel with the sea, everywhere lying nearly, if not quite, horizontal, but these strata present the character of æolian rocks modified by the action of the sea.

On Grace Island, Hawkins Island, and off the Quarantine in Hamilton Harbor, we traced most distinctly, at low-water mark, æolian strata dipping at a high angle into the sea, and yet at many points they have passed into what is called base rock by the complete obliteration of the knife-edged strata from the abrading, the cementing, and the solvent action of the sea. The third island south of the Quarantine, Post Island, and Darrel Island all present the same phenomena of modification of the æolian rock into base rock. In the interior of a cavern leading into Quarantine Island we could trace the dip of the æolian rocks into the sea, and the same was the case at Hanson's Island. On the southwest side of Post Island the fine æolian lamination could still readily be detected below high-water mark through the "base rock" coating.

Nowhere in the Bermudas have I found corals above high-water mark or higher, the presence of which could not be accounted for by the action of high winds or waves during hurricanes, and surely the presence of caves above high-water mark is not in a limestone district an indication of elevation. If the explanation I have given of the formation of base rock is correct, its existence at a height of a few feet above high-water mark is not a proof of elevation.

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[1] Thomson, Atlantic, I. 307.

[2] There was no "base rock" found while cutting through the æolian strata during the excavation of the Ireland Island Dry Dock.

## FOSSILS.

On a small island to the south of Agers Island I found quite a number of species of marine shells identical with those now living embedded in nearly horizontal æolian strata a few feet above high-water mark. Also a bank of Chama evidently thrown up or blown up during a hurricane, much as we find Strombus on some parts of the Bahamas thrown up in great banks high above high-water mark. That marine shells should thus be thrown up or blown up to such considerable heights in what may, in proto-Bermudian time, have been a protected sound, as well as is Hamilton Harbor, is not extraordinary. We need only recall the great violence of the hurricanes which sweep past and over the Bermudas, during which vessels have dragged their anchors in the sheltered inner harbor of Hamilton, where the wind and sea have a comparatively limited range.

Below that, but in æolian strata, these fossils extend to low-water mark, apparently embedded in the "base rock." These lower strata have at first sight all the appearance of beach rock; they consist mainly of particles larger than æolian sand, which probably have not been blown a great distance upward from their base. But these strata, consisting of larger brecciated fragments, have, like other æolian beds, been changed into the hard ringing limestone so characteristic of nearly all the exposures below high-water mark.

During the very low tides which prevailed for the last days of my visit at the Bermudas, I was able to trace the existence of æolian beds underlying the fossiliferous beds with the base rock lying between them. The fossils are embedded in æolian rock, and in certain spaces, which have become cemented so as to destroy the laminations, they appear to be embedded in the base rock. The existence of these fossiliferous beds above high-water mark in the islands of Hamilton Harbor has led Rice to assume a period of slight elevation as having occurred in the Bermudas, and further to maintain that much of the interior of the islands is underlain by beach rock, a statement with which Professor Heilprin agrees in the main. The size of the material and the broken shells thrown up at Shelly Beach show how high up material similar to it may, even under ordinary circumstances, have been thrown up and become embodied into æolian beds without its being any indication of a period of elevation.

The fossiliferous strata of St. George Island,[1] mentioned by Professor Rice, seem to me to belong to the same category of rocks which crop out in Hamilton Harbor. They are æolian rocks containing many species of Lucina, Chama, and the like; and as all the marine shells near Agers Island must have found their way into these æolian strata under the action of the winds or the sea, the parts of the strata below high-water mark have here also been partly changed into the hard ringing limestone of the base rock. Professor Heilprin also found marine shells in æolian rocks.[2] In a hill to the eastward of Stone Hill I have found a few recent land shells in very friable æolian rock.

An interesting collection of rocks and sub-fossils from the æolian rock quarries and other localities is preserved in the Government Building. It contains among other specimens a small collection of casts of Tellinas and Lucinas obtained from a submarine cut in Tomlin's Narrows, sixteen feet below low-water mark. This would indicate the existence of a bay or sound, as in our day, at the time when the level of the sea was higher, before the land had by subsidence obtained its present level, and it is no indication of elevation any more than the presence of the living shells of to-day as fossils would indicate such a change. It also contains the shell of a tropic bird egg found in æolian rock quarries in the Middle Road in Devonshire, the bones of a snipe? obtained from æolian rock near St. George, and marine shells from a bed twenty feet above the sea and one hundred feet away from it, occurring in æolian rock on the main road from the north side of Gibbs Lighthouse Hill. There is also in the Government collection a large Turbo, which was found in a cutting in æolian rock at the east end of Hamilton; this Turbo is said to be extinct, but is found sub-fossil in the highest æolian hills.

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[1] I would consider the peculiar conglomerate of Stocks Point as only the higher limit of a local beach rock, which may have been thrown up in a locality specially exposed to gales or hurricanes, and limited in extent. It contains fragments of the underlying drift rock, and resting upon it, as Rice observes, is the ordinary drift rock. But on both sides of the beach rock we find æolian drift rock reaching to the sea, which would indicate either a fault or that the conglomerate was older than the æolian hills of the Bermudas, neither of which suppositions is in accordance with other facts observed in the vicinity.

[2] "At several points, more particularly along the north shore, I found marine shells (Lucina, Tellina, etc.) embedded in unquestionable drift rock, and indeed it could hardly have been expected that such association should not occur. . . . The same is also true in a measure of the occurrence of land snails. . . . One of the commonest shells of the lower drift rock is the large *Turbo* (*Livona*) *pica*, a shell which appears to be very abundant about the coast." Heilprin, Bermudas, p. 35.

## THE SOUNDS AND LAGOONS.

**Plates II., IV., VI., VII., XIV., and XXVII.**

The sounds are sinks and depressions filled with sea water, as was first suggested by Rein, and none of them are secondary atolls. They owe their origin either to the breaking through of low saddles dividing sinks from outer lagoons, or to subsidence, allowing the water of adjacent lagoons or the sea to flow in over separating ridges, or to both these causes.

Professor Heilprin gives an excellent description of the rapid waste which the islands are undergoing, and of the formation of the sounds, on pages 36 and 37 of his Bermudas.

The improbability of the sinking of the roofs of large cavernous areas to form the sounds, as has been suggested by Rein[1] and Fewkes,[2] does not militate against local disruptions on a limited scale, of which, as Heilprin states, there is abundant evidence.[3]

The lagoons of the south shore between Tuckerstown and Newton Bay are brackish pools separated by low hills from the sea (Plate XIV.). In many places it would require comparatively slight inroads of the sea, or but little subsidence, to change them into diminutive harbors or sounds, similar, but of course on a smaller scale, to Castle Harbor or Harrington Sound. The shore platforms of Harrington Sound and Castle Harbor are similar to the ledges which extend off the cliffs from the outer shores of the islands (Plates VI., XXVII.).

Harrington Sound seems to have been formed in exactly the same way as the smaller harbor indentations of the coast. Its shores present all the phenomena of disruption by waves exhibited by the outer shores, although in a less degree. The action of the sea is of course much less powerful, yet is sufficient to have undercut the cliffs, and in some places, as on the north shore of the sound, they are fully as high as many of the more striking cliffs formed on the sea faces outside by the splitting off of large slices of the æolian hills.

We find in Harrington Sound islands, islets, and many honeycombed ledges (Plate XXVII.), pinnacles, and mushroom-shaped rocks, due to erosion or to the solvent action of the sea, differing in no way from those made along the north and south shores of the islands. Along its shores there are numerous ledges running out from or parallel with them, extending between the small rocky promontories, which if cut off would form a series of patches close to shore similar to those which extend from the north shore inside of the banks towards the outer ledge flats and upon them. Gorgonians, corals, and other growths, have settled upon the ledges since the time when they and the saddles have sunk or have been eroded to their present level, giving the sea access into the interior of the various sounds so characteristic of the Bermudas. This is admirably shown by the cutting of the sea into St. George Harbor, so as to give access to it both from the outer and inner waters of the bank. These passages are narrow, so that corals do not get a sufficient supply of fresh water, and hence are far less common than on the shelves of Castle Harbor, which is freely connected with the sea on its southern exposure. In Harrington Sound the connection with the lagoon is still less open, a narrow cut on the north being the only opening through which the inner waters of the bank gain admission to it. Castle Harbor in the same way is connected freely with the sea on the south, and but slightly with the inner waters of the bank, through the same opening which connects them with St. George Harbor.

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[1] Rein, Bericht., 1870.

[2] Fewkes, J. W., Proc. Bost. Soc. Nat. Hist., 1887, p. 518.

[3] Bermudas, p. 45.

A narrow cut separates Somerset Island, which forms the western boundary of Great Sound, from the main island. This sweeps round to the eastward and forms the southern flank of Port Royal Bay, which is separated from Great Sound by the line of islands extending outward from Tucker to Darrel Island (Plate II.).

The depth of water in the sounds is very considerable, not only in the sounds themselves, but also in the inner waters of the reef, which have been called lagoons, but are hardly such in the sense in which that term is understood. It would greatly conduce to accuracy to call the inner basins of deep water — surrounded on one side by the outer ledges of the reef, and on the other either by the connecting patches of ledges or by the islands in part — sounds also, for such they undoubtedly are, and were sounds similar to those now existing and known as Great Sound, Port Royal Bay, Hamilton Bay, St. George Harbor, Castle Harbor, and Harrington Sound.

In Great Sound we find from ten to eleven fathoms. In Harrington Sound as much as twelve fathoms is found in several spots. In the outer sounds we do not as a general rule find so great depths. What we may call the Brackish Pond and Bailey Flats Sound has a general depth of only from five to six fathoms. The great sound known as Murray Anchorage, to the northeast of Bailey Bay Flats, is somewhat deeper, and varies from seven to nine fathoms. To the north and northwest of Murray Anchorage the water is still deeper, varying from seven to ten fathoms, with a deeper bight to the northeast of Three Hill Shoals. where the depth is twelve fathoms close to a spur of the East Ledge Flats. These depths all run close to the five fathom line, which may be called the inner edge of the outer flats or ledges extending from East Ledge to the Ledge Flats north of Blue Cut. On these the depths vary from one and a half to four fathoms, with occasional deep holes, with a white sandy bottom, or islets separated from the edges of the Ledge Flats or inlets running in from the sounds, and patches surrounded by from seven to ten fathoms. To the westward of Three Hill Shoal the clear bottom averages from seven to eight fathoms. In the sound between Brackish Pond Flats and Elies Flats the depth varies from six to ten fathoms, with occasionally a five fathom sounding between the numerous isolated patches of ledges inside of the five fathom line. The extensive sound to the west of Wreck Hill, extending to the Western Ledge Flats and southwest of Elies Flats, varies from seven to eleven fathoms (Plate II.).

In St. George Harbor the bottom is hard in five fathoms. The dredge brought up many specimens of Toxopneustes and Echinometra. We found only a few patches of Gorgonians and of massive corals in the harbor itself, while in Castle Harbor, which has a freer communication with the sea, the patches of corals on the ledges are quite numerous, having much the same characteristics as those of the Ledge Flats.

In Harrington Sound the growth of Gorgonians and massive corals is also less prominent than in Castle Harbor, and the development of Gorgonians, Algæ, corals, and corallines in these sounds, as well as in the sounds at the western end of the islands (Hamilton Harbor, Port Royal Bay, and Great Sound), seems clearly to indicate that as fast as they became connected with the outer sounds and in proportion to the accessibility of the sea, corals have gradually found their way into these sounds, and have also developed in proportion to it, being less abundant in sounds indifferently connected with the open sea. All the conditions of the coral growth indicate a comparatively recent inroad of the sea, first into Castle Harbor, next into St. George Harbor, and finally into Harrington Sound. The corals have found their way into the sounds much as the corals forming the veneer of the outer reefs have found their way from the West Indies in the track of the Gulf Stream, or perhaps have been derived from the corals forming the proto-Bermudian reefs, which in their turn were introduced from the West Indies through the same agency.

It seems probable that the cedars dredged up in the excavations for the channel in St. George Harbor were floated into the basin from the adjoining hillsides; but in the case of the red earth coming from the excavation in Ireland Island, the site of the present dockyard was probably a banana hole, which during the subsidence sank to its present level, say fifty feet or so below low-water mark.

The conditions of growth of the corals in the sounds of the Bermudas do not seem to me to have any bearing on the growth of corals in the lagoon of an atoll. The lagoon of an atoll swept by the currents, with its rim pounded upon by the surf, and the Bermudian Sound, with its comparatively quiet expanse of water formed under such different conditions, do not seem to have many features in common.

There are near Harrington Sound, between it and Castle Harbor, three small sounds in the process of formation, which present all the characteristics of the larger sounds, only on a most diminutive scale in proportion to the range of the sea they enclose. The two most interesting are one to the east of Harrington House, and one called Webb's Pond, on the road to St. George, after passing the Flats. The latter is an irregularly pear-shaped, miniature sound, about 200 by 180 feet, and perhaps 200 feet from the north shore. At its southern extremity there are low crumbling cliffs. The depth is said to be fourteen feet. Both of them are merely sinks close to the sea, but only connected with it under ground, and perhaps filled by percolation of the sea through the æolian rock. The tide rises and falls in both.

Spittle Pond, on the south shore, is a brackish sink surrounded by grassy shores, which barely reaches high water-mark. Between Tuckerstown and Newton Bay there are also a couple of brackish ponds, the shores of which are protected by mangroves.

While the sounds undoubtedly indicate subsidence, they are not lagoons surrounded by corals, such as we find in atolls, and should not be compared to them. They are sinks or low tracts, which have become connected with the outer waters into which corals have found their way. Such sinks we find ready to be changed to sounds or pseudo lagoons at many points of the Bermudas; as, for instance, along the South Shore road from about Walker Bay nearly to Hungry Bay, there are a series of low valleys about at the sea level, and separated from the sea by a ridge of low æolian hills. A further slight subsidence would change them into shallow harbors by the rushing in of the water over the lowest of the dividing saddles. A similar low tract extends to the south of Government House between it and Hamilton, with an outlet into Boss Bay.

## DISTRIBUTION OF THE CORALS.

The Bermudas are the most northerly limit[1] where reef-building corals are known to occur, unless we can call coral districts areas where Astrangia, Primnoa, and other northern types, like Caryophyllia and Lophohelia, are to be found.

The absence of Madrepores, to which Thomson called attention, is very striking. There are thus wanting the very elements to supply the bulk of the material broken off and thrown up by the sea to accumulate as beaches or islets.

It is interesting to note that the littoral marine fauna of the Bermudas is the same as the shallow water fauna of the West Indies, and that its existence here is one of the finest examples of the effects of great oceanic currents in shaping the geographical distribution of animals the embryos of which are pelagic a sufficient length of time to be transported to this their northern limit from the Bahamas and other parts of the West Indies. During my stay at the Bermudas, every day when the wind blew from the southwest or west the common West Indian Physalia appeared in great numbers.

Besides marine animals, floating masses of wood coming from the West Indies are frequently stranded on the shores of the Bermudas, these sometimes carrying fragments of rocks. A large ellipsoidal mass of floating pumice, measuring eleven inches in length, was picked up off the south shore by the Hon. Archibald Alison. A similar float, thrown up on the south shore, is preserved in the Museum of the Government Building. This piece is filled with red earth.

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[1] The minimum temperature of the surface of the sea occurs in January and February, when it varies between 59° and 63°. In March it varies from 62° to 66°. In April its maximum has already risen to 71°; in May the maximum is 76°, minimum 70°; in July the minimum is 79°, maximum 82½°; in August the maximum is 85°, minimum 82½°; in September the maximum is 83°, and the minimum 75°. The temperature then falls rapidly from 69° and 74° in October, down to 61° and 65° in December. The minima are remarkably low temperatures for a coral reef district. The above data were kindly furnished me by Mr. John C. Watlington, of Hamilton.

Wallace lays great stress upon the pumice thrown up from the sea as being a possible explanation of the source of red earth. Although I examined the beaches of the south shore many times, I never succeeded in finding a single piece of pumice. Red earth is abundant, both at the Bahamas and Bermudas, in localities to which drift pumice could not have access.

I was greatly struck with the apparent want of adaptation to their surroundings of the coloring of many of the Bermudian marine invertebrates. The dark violet Diadema and Echinometra are very common on the faces of the steep rocky patches, as well as in the sandy hollows of the surface of the bank. In the one case they are part of the brilliant patchwork forming the coloring of the reef surface; in the other, they stand out most prominently against the whitish Nullipores. Diadema in Florida, as well as in the Bahamas, is often found in colonies entirely filling the bottom of some sandy depression in the midst of a white field of surrounding coralline bottom, the patches of brilliantly colored corals and Gorgonians themselves standing out as a whole in striking contrast to the whitish bands of coralline or æolian sand separating them.

Professor Heilprin has greatly added to our knowledge of the fauna of the islands,[1] which was previously mainly derived from the sketch of their Natural History by Jones,[2] and has also given a list of the species of corals belonging to the islands.[3]

The low tides prevailing during the last days of my stay at the Bermudas enabled me to note the luxuriant growth of Millepores and Gorgonians on the surface of the many patches which were nearly awash during these days. The flats extending to the north of Ireland Island, and the flats to the southeast of the North Rock Ledge, were specially noteworthy for their abundant coral growths.

On passing through Mangrove Bay to reach Hogfish Cut from Great Sound, we dredged Oculinæ from the deepest part of the bay; the bottom in four fathoms is very fine sticky silt, almost marl. Corals in Hamilton Harbor, Great Sound, and Port Royal Bay are limited to a very scattered growth along the shores of the islands of these sounds below low-water mark. In the deeper parts of the sounds Oculinæ grow to considerable size. Zoanthidæ are abundant on the higher knolls of the outer reef, and also on the serpuline atoll-like structures. Porites is quite common on the outer reef. This is in marked contrast to the abode of Porites in Florida, where it is usually most abundant on flats more or less sheltered.

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[1] Bermudas, p. 97.

[2] The Naturalist in the Bermudas.

[3] Bermudas, p. 98.

The corals at the Bermudas as well as at the Bahamas do not generally reach the surface. They form a more or less connected belt of coral growth in from five to six fathoms on the inner edge of the flats to the outer limits, the beginning of the broken ground, the corals extending to eight or ten fathoms on the southern sea faces of the flats.

## LEDGE FLATS AND PATCHES.

**Plates II., XV., and XVII. to XXVI.**

The ledge flats, patches, or coral heads, are names given to different parts of the reef, which has universally been considered to owe its existence to the growth of corals, and much of the confusion existing regarding the structure of both the Bahamas and Bermudas is due to the fact that corals have been assigned a part in the building up of these islands which they have never performed.

The flats consist, not of coral heads, though they are often so called both here and at the Bahamas, but of ledges of æolian rock rising from a depth of five to six fathoms or more (Plate XVIII.). These ledges, with their nearly vertical sides and their slopes deeply honeycombed, drop rather abruptly into the coralline bank bottom, which forms more or less extensive irregularly shaped patches separating the ledges. The surface and sides of the ledges are veneered by corals,[1] Gorgonians, and Millepores; the sharper edges of the ledges are covered by incrusting masses of Millepores, and calcareous and other Algæ grow in great profusion between the corals and Gorgonians. The Millepores, Gorgonians, Nullipores, and calcareous and other Algæ, are by far the most abundant growth on the inner patches. On these we find only comparatively few of the larger Mæandrinas and Astreas. The massive corals increase greatly in number as we approach the outer edge of the reef, and the finest and most numerous specimens appear to grow on the outer sea face in from five to seven fathoms of water. Beyond that, or even at lesser depths, in five to six fathoms, the broken ground begins. This consists mainly, as far as I could ascertain from the observations of others and gather from my own notes and dredgings, of Gorgonians, masses of Algæ and of coralline Algæ, and Nullipores, with comparatively few massive corals. As far as I am aware, this broken ground does not extend on the northern sea face of the ledges as far out as off the southern ledges, where the fishermen report its existence to a depth of from sixteen to seventeen fathoms.

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[1] Thomson thinks that the patches have been built up by the corals. Atlantic, I. 304.

The ledge patches rise in steps from the coralline bottom depths, much as they fall in successive ledges off the shore cliffs. As we approach the bank edge of the flats, the ledges become smaller, the depth of water increases, and the sand spaces between the patches increase, often forming long tongues extending into the main body of the ledges of the flats. Many of the ledges near the edge come quite close to the surface, and a great number are awash at low water, although the depth of water between them is greater than at the point we might call the crest of the ledges. The nearer we come to the breakers, the greater becomes the wear of the sea slopes of the ledges, so that in many places their slope is quite abrupt, from two or three to five fathoms, and a somewhat gentler slope extends from that point seaward to form the broken ground.

The high æolian cliffs of the south shore probably extended to the outlying reef, which is itself only a series of ledges running parallel to the coast, the crests of which are bare at low water. On these and the inner irregular flat ledges which dot the bottom over greater or smaller areas between the outer ledges and the shore grow corals and Gorgonians, — a comparatively thin veneer, which supplies, when dead or beaten off by the surf, a part of the material which goes to form the sandy beaches of the south shore, — though by far the greater mass of the material is derived from the disintegration of the ledges themselves. So that the submarine remnants of the ancient æolian hills supply the material which to-day creeps over their faces and finds its way inland, much as they in their own time must have crept over the lowland existing within the limits of the proto-Bermudian coral reef.

From the observations I have thus far made, it seems to me as if the corals now growing at the Bermudas had, as at the Bahamas, played a very unimportant part in building up the mass of the reefs. It is true that some of the flats are largely formed of coralline coral and æolian sand, derived in part from the coral patches which line their faces. But as yet no islands or islets have been formed by their disintegration, showing that the coral growth is not rapid; and although in some of the patches along the inner edges of the flats and on some of the connecting patches the corals have attained sufficient thickness to conceal the original ledges, and perhaps in many cases to build them up from a couple of fathoms or so to within the limits of low-water mark. Their growth can in no way be compared to the massive coral reef structures we find in the West Indies and Florida.

Off the north, as well as off the south shore, the patches nearest the land are merely ledges consisting of larger or smaller pieces which have become separated from the shore cliffs by the action of the sea, or else they are more extensive patches marking the position of small islands, islets, or rocks which were once more or less closely connected with the main island, and which now run as ledges parallel to the shore line. These ledges, if close to the shore, are barely covered by Algæ and a few barnacles, or Mytilus, or isolated corals, or such animals and plants as we find on the immediate shore line. Farther from the shore they become overgrown with a greater profusion of Algæ and Nullipores. As we proceed from the north shore to the ship channel, we gradually come upon ledges on which are found corals and Gorgonians, Algæ and Nullipores occurring as on the ledge flats, but in less profusion. It is on the outer ledge flats, which have probably been under water longest, that we find the most abundant growth of corals. While I do not deny that some of the ledges have been increased in height, and slightly in width, by the corals covering them, yet the corals have played but an insignificant part in building up the ledges themselves. The ledge flats are the remnants of the proto-Bermudian æolian land worn down by the action of the sea to a certain level, and upon these æolian ledges forming the underlying foundation of all the patches, the coral reefs — viz. corals, Corallines, Gorgonians, and Algæ — have grown, but only as a comparatively thin veneer upon the pre-existing æolian ledges.

The surface of many of the ledges outside of Hungry Bay on the south shore, exposed at low water, is covered with coral growth, especially the ledges on the inner face of the outer patches of the south shore reef. The ledges exposed at extreme low water are irregularly shaped, rising from two to four fathoms of water; they are greatly undercut and abraded, and show signs of the solvent action of the sea. The vertical and sloping faces of the ledges near shore are covered and protected from wear by a thick growth of Algæ and Corallines, similar to the growth which protects the upper face of the ledges. But on the upper surface there is in addition an abundant growth of Serpulæ. Between the outer ledges and the shore, more or less protected by the isolated outer patches extending to the reef, a sort of lagoon is formed. In this lagoon are found numerous ledges; then, closer to the shore, overgrown with Algæ, Corallines, and Serpulæ, there is deeper water, with corals and Gorgonians. Many of the ledges within the lagoon consist of the miniature serpuline atolls and reefs described in another section of this Report.

On the inside of the outer serpuline reef ledge, corals and Gorgonians flourish, according to the depth and the position of the ledges intervening between the outer reef and the shore. Off Sinky Bay the bottom outside of the outer reef ledges is hard. Off Castle Harbor, as far as the channel leading into St. George Harbor (Plate XXI.), we can readily trace the gradual formation of islands and islets originally constituting the continuous barrier to a sound formed by the breaking through of the lower saddles of the ridges dividing it from the sea. The outer row of these islets and islands differs from the inner one in having comparatively wide ledges, projecting round the base of a central pinnacle more or less undercut. As the central pinnacles are cut away, they leave only a narrow ridge on the broad platform, the ridge itself also disappears, and on the outer line of ledges have grown Algæ, Serpulæ, and other organisms, which prevent in some cases the further wearing away of the whole ledge, protecting its most exposed parts. The sea breaking upon the upper surface of the ledge soon forms the more or less regular serpuline atolls and "boilers" of the south shore which will be described later on. They are found on all the breakers on the outer side of the reef ledge flats, like Mills Breaker, the North Rock, and others; serpuline reefs extend off the headland on the west of Church Bay. The Southwest Breaker is the westernmost of the line of serpuline reefs skirting the south shores. It has three "boilers" on it, a long one and two smaller ones, with a small serpuline atoll to the southwest of the main ledge.

There are on the eastern part of Castle Harbor itself a number of ledges coming to within a foot or two of the low-water mark. They are covered with corals and Gorgonians, Algæ and Corallines. The Gorgonians are not very flourishing, but the Nullipores and Algæ grow in abundance between the massive corals. The patches are separated by a fine sandy bottom. On the outside of Castle Harbor there are many coral patches, boilers, and ledges extending outward of the outer ledge, to a depth of from seven to eight fathoms, with an occasional ledge rising from ten fathoms (Plate XXI.). But, as a rule, outside of the outer reef ledges we come upon the "broken ground."

The line of reefs to the south of the island extends unbroken from St. David Head to off High Point. The ledges are all æolian shore cliffs which have become separated from the island by the action of the sea, then beaten away, abraded and eaten into by the surf, and, according to their position, the depths in which they are found have been transformed into the peculiar agglomeration of reefs and ledges off the south shore. They form an incipient ledge flat, as it were, of which the outer line is still very prominent, and which the outer breakers have not as yet undermined and eaten away, so as to leave, as they do round the ledge flats, only a few isolated rocks cropping to the surface. Some of these ledges are a hundred and fifty feet in length, and even more, with a breadth exposed at low water varying from two or three feet to thirty or forty feet; others are only small pinnacles a few feet in diameter. All, however, present nearly vertical faces, and rise abruptly from two and a half to four fathoms. They are all more or less undercut, eaten away, of irregular mushroom shape, and the breaking up and disintegration of the exposed pinnacles after they have been so undermined as to break from their base supply a large amount of the material thrown up on the beaches.

A section along the slope of the sea beach of the south side of the island shows first a shore line of flats, ledges, and pinnacles, then a second or a third row of mushroom-shaped undercut rocks, some reaching to above low-water mark, others barely awash, or a few feet below. A few of the ledges may still be surmounted by æolian rock pinnacles, while the submerged surface of other flats is either protected by Algæ, Corallines, or Serpulæ, and according to their depth they are changing or have been changed into serpuline reefs. A few of the ledges in deeper water inside of the outer line of ledges are covered with corals and Gorgonians. The outer row of ledges forming the reef do not differ from the rows of rocky ledges inside of the reefs, or from those close to the shore. There are on the outer lines, however, no ledges surmounted by pinnacles, most of them having been changed into boilers, or into long ledges with winding or S-shaped vertical walls, the surface of which is protected by Algæ, Serpulæ, and other growths. Outside of the outer row of ledges we come upon the broken ground bottom, which consists of flat ledges extending from five to fifteen or more fathoms. Upon these in the shallower parts flourish the massive corals and Gorgonians, while over the deeper parts extend mainly the Gorgonians and Algæ, as well as Corallines. Such broken ground bottom occurs off Chaddock Bar, off Long and Little Bar, off the Chub Heads, and all the way from the Southwest Breaker outside of the south shore reef to off Castle Harbor and off St. David Head. Similar broken ground occurs wherever on the Admiralty Chart it is marked *r*, — off the Mills Breaker Channel, outside of the North Rock Channel, the Eastern and Western

Blue Cuts, and Chub Cut, as well as between Long Bar and the West End Ledge Flats. There are outside of the reefs many areas of rocky bottom, marked *r* on the chart, the remnants probably of extensive æolian ledges.

Nowhere do we find more fantastic shapes in the pinnacles remaining on some of the ledges than those which are seen to the south of Nonesuch Island, and extend to the eastward toward St. David Head. The islands pass into pinnacles, into ledges, and finally into boilers, in regular succession, and in proportion to the exposed condition of their position. Similarly eroded pinnacles are also seen on a smaller scale, but of fully as fantastic shapes, in St. George Harbor, in Mullet Bay, and on the south side of the causeway on the western side of Castle Harbor.

The patches outside of the reef off the south shore can be clearly seen extending a short distance to sea, separated by irregular white patches of sand. The inner ledges, forming the patches between the outer reef and the shore, are most capriciously distributed. Outside of the reef off the south shore the corals do not seem to thrive, and the broken ground is comparatively barren, though we find an occasional patch where Gorgonians, Algæ, and massive corals are more abundant. The coral growth is more that of the broken ground than of the reef flat ledges or of the connecting patches.

Heilprin has noted the great importance which the Millepores take in the composition of the bank sand bottom. On the south shore, where Serpulæ are so abundant, the fragments of their pinkish shining tubes can readily be distinguished in the coarser fragments of the sand thrown up on the many beaches along the shore. While in the Bahamas I was struck by the importance of the Millepores in the economy of the reefs. They seem to be far more abundant there than upon the Florida reefs, where the Madrepores take an extraordinary development, while they are absent in the Bermudas.

The south reef extends at a distance from the coast of about one thousand to fifteen hundred feet throughout its length from the entrance to St. George Harbor to the eastern side of Hogfish Cut. It has nothing to do with a barrier reef as such. It is a barrier ledge of æolian rocks derived from the old shore line, and not a barrier reef formed by corals, as Heilprin would lead us to suppose. The description which he gives of the work of destruction going on upon the barrier reef which skirts the southern coast is somewhat unfortunate, as the material of which he speaks as "blocks of coral and of coralline . . . detached and broken," is derived from the rehandling of the ledges of æolian rock of the former sea-shore. The corals now growing play an infinitesimal part in the forming of the sand dunes which "stand on the eminences which to-day are the Bermudas." His description would apply to the original reefs from which the Bermudian hills were formed, but is scarcely applicable to the work doing in our day.

Heilprin, after quoting Dana's description of the reef of an atoll, finds it largely applicable to the condition of the Bermudas, an opinion to which exception must be taken. From what has been said it will be seen that the Bermudian coral reefs have little if anything in common with the coral reefs of an atoll. Certainly no more erroneous statement could be made than that "the more seemingly favored patches are the creations of the surf themselves." The Bermudian reef corals are, like the Bahama reefs, submerged, rarely come to the surface, and have not supplied any considerable part of the material which has gone to build up an extent of land either in the Bahamas or the Bermudas. In the Bahamas the corals flourish most profusely in depths of from five to twelve fathoms; at the Bermudas six to seven is their limit, and those on the sea face of the ledges do not seem any more abundant than those on the edges of the flats. I was not able in the several sections I made across the sea faces of the southern reef to find the unbounded profusion of coral growth which Heilprin observed. In fact no one has better shown than he that the coral reefs which now encircle the Bermudas have had no share whatever in their formation, and I fail to see how the fact that subsidence has given to these islands their outline of to-day has any bearing upon the theory of the formation of coral atolls by subsidence. Any land surface exposed to the action of the inroads of the sea owing to its subsidence would have been eroded to some extent according to the nature of the rocks composing it. The subsequent formation of a thin veneer of coral reefs upon its sunken ledges would not have any bearing on the theory of the formation of thick masses of limestone by subsidence. It may be interesting, in this connection, to refer to Heilprin's statements "that the present form of the Bermuda Islands bears no relation to the ring of an atoll," and that "the existence of an atoll is not demonstrable."[1]

I fully concur in what he says regarding the subsidence which followed the elevation of the islands to their greatest height. Heilprin was impressed by the absence of loose boulders of rock (coral?).

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[1] Bermudas, p. 46.

This is natural, for we find on the ledges of the Bermudas mainly æolian rock masses readily crumbling to pieces, a thin coral belt, and but little solid material to be shaped into boulders by the sea, and similar to that of reefs studded with massive corals and Madrepores, which are usually crowded with boring Annelids, Sponges, and Mollusks, and which thrive in such localities, but find nothing to feed upon in the æolian rocks forming the base of the ledges of the Bermudas, or in the æolian sand flats, the bottom of which is constantly kept in movement. One finds only occasionally on the beaches of the south shore very limited deposits of flattened pebbles composed of corals, fragments of æolian ledges, and shells of Nassa.

We can readily follow off the north shore of St. George the transition of the æolian shore ledges into mushroom ledges, or other patches gradually becoming coated with coral growths as they come nearer the main channel into deeper water towards Murray Anchorage. We find here also a few serpuline atolls and fragments of vertical walls protected by Algæ or other growths. Sargassum, Algæ, and Corallines are especially abundant on the inside ledges.

The ledges I have examined immediately north of the main channel, the southernmost patches of the connecting ledges, all present a very similar structure. They are deeply eroded on the sides and surface. Sometimes one side drops nearly vertically from a depth of two to three feet at low water to six or seven fathoms. The top is more or less flat, resembling the ledges near shore, and differing from them only in being covered by a thick growth of Algæ and Corallines, which protects their sharp edges and ridges from the effects of the sea. The other faces are more or less sloping, dropping in steps much as the shore cliffs do, and they are more or less undermined and honeycombed. One can sometimes trace what may perhaps have been the low-water shelf of the ledge before the subsidence had reached its present height, when it was a part of the old shore line cliff, or one of the outlying rocks or islets.

On the Devil's Flats there are large patches which have in some cases been covered with bank sand, leaving the æolian rocks exposed only on the outer edges, where they are covered with the usual coral growth. In Port Royal Bay, in Great Sound, and in Hamilton Harbor there are many rocky patches rising above the sandy bottom on which Oculinæ are growing. Along the north shore the rocks are generally thoroughly honeycombed immediately above high-water mark; between that and low-water mark they show signs of abrasion and of the solvent action of the sea. The low shore cliffs usually extend from low-water mark outwards in shelves of very varying width, terminating either abruptly, or passing into deeper water, either by one or more steps, or by a gradual slope. The shelf immediately above low-water mark is usually protected against abrasion by species of Algæ, or small barnacles, or patches of Serpulæ or Mytilus, or a thin coating of Nullipores, while below or at low-water mark Sargassum and coralline Algæ begin to grow.

It is easy to trace out on the chart the former connection of the flats with the present land surfaces in all directions. The evidence obtained from an examination of a number of ledge patches between the north shore and the south side of the main ship channel is most conclusive that all these patches are only æolian ledges, parts of the cliffs which once were connected with that shore and have become separated from it by causes similar to those now acting upon its cliffs. Upon these ledges have gradually grown Algæ, Corallines, a few Porites, Gorgonians, and Millepores. When the patches are close to the shore Algæ predominate.

The shore cliffs extending into the sea usually have vertical or steep faces, and one can readily follow their indented and honeycombed outlines to a depth of three to four fathoms or more, where the base of the cliff passes abruptly into the coarse bank bottom. An examination of the patches to the north of the main ship channel shows ledges with the same structural features, except that their surface is more thickly coated with corals, Corallines, and Algæ, as well as Millepores; we find also a few indistinct serpuline atolls on these patches, but their number cannot be compared with those of the south shore. Many of the ledges are only protected by small barnacles and Algæ. Off Bailey's Beach there is a row of isolated cliffs and ledges forming an outer barrier to the bay, the remnants of the hills which once separated what now forms Bailey's Bay from the sea. The interior patches of ledges are more isolated; they stand out vertically, or nearly so, in from five to six fathoms of water, while those in deeper water nearer the outer belt of ledges may be more or less choked and covered up by the masses of coralline and æolian sand constantly accumulating and forming there.

Some of the ledges which are not too far removed from the shore line, like those off Bailey's Beach or some parts of the north shore off Spanish Point, are most instructive as showing ledges which still are capped by æolian pinnacles, of which the æolian stratification is most distinct. In the submerged base of these pinnacles the stratification has completely disappeared, and between high and low water mark the æolian rock has been changed into a hard compact ringing limestone, more or less worn and honeycombed by the solvent, as well as the mechanical action of the sea. This irregular honeycombed and cavernous surface extends to the base of the ledge, where it passes into the coarse bank bottom. The base of the ledge may spread somewhat, or it may have been greatly denuded above low-water mark, so as to form a wide base for the æolian pinnacle surmounting it. The interesting feature, however, is to trace the gradual increase of coral and Gorgonian as well as Nullipore and Coralline growth upon these ledges below low-water mark, as we examine them both in deeper water and at a greater distance from the shore. So that when we reach a certain distance from shore where ledges surmounted by æolian pinnacles are rare, and where we find only ledges reaching up to low-water mark, we soon pass into the coral patches, where the coral growth has become so vigorous that it appears at first glance to have been itself the builder of the patches, having so completely buried under its coating the æolian ledge which constitutes its foundation. Unless one has traced the gradual development of these coral patches from æolian ledges through all their transitions, such an interpretation would be most natural.

The rocks and ledges off Craw Point out to the ship channel, and the rocks and ledges off the north end of Shelly Beach (the Stags), leading to the outer patches as far as the south side of the main ship channel, all tell the same story. We have everywhere the gradual change of an æolian cliff which has become detached from the shore passing into a ledge, and, according to the distance from the shore and depth of water becoming a ledge coated with Millepores, Algæ, Corallines, and coral growth, known as "coral heads." The more massive corals and forests of Gorgonians thrive better on the patches near the flats, or on the ledge flats themselves. There is a fine lot of patches to the westward of Mangrove Bay; they are æolian ledges close to Ireland Island, which gradually pass into coral and Gorgonian patches as one goes to the westward.

To the west of Mangrove as well as to the west of Daniel Island the patches are in comparatively shallow water, and are surrounded by great stretches of sand, the ledges being more widely separated and cropping out in greater number close to the outer edges of the sand flats. Gorgonians and Millepores flourish mainly on the inner flats, while corals grow, but not in abundance, on the outer ledges. These sand flats with pretty steep slopes seem to be due to the disintegration of great numbers of ledges which must have yielded more readily than ledges elsewhere on the bank to the destructive agency of the sea. An examination of the ledges of the great sound bounded by the Daniel

Island Flat shows them to be similar to those of corresponding position which we examined off the north and south shores of the main island, and there is nothing to show that they, any more than the ledges just mentioned, owe any considerable part of their increase to coral growth. We found here many patches of limited extent, with nearly vertical or steep faces, greatly honeycombed, and worn and covered with Algæ, Corallines, and coral growth, some of them rising from seven fathoms up to near low-water mark.

The corals on the ledges of Brackish Pond Flats increase in profusion on the patches as they increase in distance from the main channel. But the appearance of the animal and vegetable growth on the ledge is practically the same on all the ledges of the Bermudas; it is a question of quantity mainly. The greatest profusion of corals and Gorgonians, as far as I have observed them, has been found on the ledges of the flats of the northern, northwestern, and northeastern parts of the banks. The ledges and patches to the west of Ireland and Somerset Islands are connected with the patches to the westward, and form a continuous line of flats as far as the Western Reef Flats. They constitute a series of proto-Bermudian cliff ledges which have been worn away from the shore cliffs, or from the edges of former lagoons and sounds, and have been overgrown by a thin veneer of corals, Millepores, and Gorgonians.

The west shore of Somerset has been greatly encroached upon by the sea; its northern extremity has been divided into a number of islands terminating with Ireland Island and the islets flanking it. One of its extensions forms the western line of rocks and islets of Mangrove Bay. It was formerly connected with the spit running from High Point to Wreck Hill, but the sea has eaten its way through, and the islets running north from Wreck Hill are the western barrier of Wreck Bay. All along the shores numerous mushroom-shaped rocks are seen, either isolated or still connected by a basal ledge, especially in the ledge running south of Daniel Island. From Wreck Hill Bay to Ireland Island innumerable ledge patches are found, with from two to six fathoms between them. These patches extend in a wide flat to the westward, forming what is known as Elies Flat until they join the western ledge flats to the eastward of Chub Cut, where there is a narrow and somewhat intricate channel with four to five fathoms of water leading from the inner waters to the outer bank. This channel separates the Western Ledge Flats and the flats to the eastward of the Blue Cuts. The bottom of the channel is covered with massive corals, Gorgonians, and Algæ. An examination of patches which reach out from the shore, and have been disconnected from it but comparatively recently, gives us the key to the formation of coral heads and of the ledge flats. Many of these patches are not as yet covered with coral growths of any kind, and their origin can still be plainly traced. From these we pass to more distant patches, in somewhat deeper water, on which Millepores, Gorgonians, Algæ, and corallines have begun to obtain a foothold, but of which the ledge structure is still apparent. Some of the ledges and patches on the north side of Spanish Point show admirably the passage from the æolian rock cliffs, which have fallen into the sea covered only with a thin coating of Algæ, to ledges with a more abundant growth of Corallines and Algæ, and finally to patches with corals and Gorgonians at a greater distance from the shore.

The mouth of Wreck Bay is protected by a number of islands running across the opening of the harbor, the remnants of the land which once connected Somerset Island with the main island. The rocks and islets to the westward of Mangrove Bay are the continuation to the south of a series of ledges which connected it once with Ireland Island. Traces of the proto-Bermudian land are found in the many patches of ledges to the westward of Ireland Island which extend towards Green Flat and thence to the west of Mangrove Bay, reaching out to Cow Ground Flat. The patches between Wreck Bay and Daniel Island reach out to Elies Flat and connect with the Chub Cut Flat. They are the northern boundary of an extensive sound bounded on the south and west by the flats reaching to the westward of Hogfish Cut, and sweeping northerly east of the Chub Heads to join the Western Ledge Flats. Similarly, south of Chub Cut, Elies Flat is the sunken boundary of a smaller sound bounded on the north by the western extension of the Cow Ground Flat.

On the western ledges we find large patches of sand intervening between the ledges on which corals grow; sometimes these sand patches form long sand bars with coral-bearing ledges only on the windward edges, the lower ledges having been triturated into sand which is more or less shifting according to the direction of the wind.

The formation of the sand flats from the disintegration of the æolian rock ledges shows how little material the corals have supplied to form the flats; they often come up close to low-water mark, and yet no coral sand islets have been formed anywhere on the ledge flats, either near the outer reefs or on the interior flats. These sand patches gradually pass into the ledges forming the outer flats, where the coral growth is most abundant and gradually diminishes on the sloping ledges of the sea face to a depth probably of twelve fathoms. The finest corals and Gorgonians appear to have their limit at a much less depth, in from five to seven fathoms. Beyond this depth the broken ground sets in, which the fishermen state that they can trace to seventeen or even twenty fathoms.

The ledges on the sides of the causeway connecting St. George with the hills to the east of Harrington Sound, together with the flats which connect them, indicate the former existence of a chain of hills which have been disintegrated. These flats form the platform of the east and north sides of Castle Harbor, and they give us an explanation of the sand flats to the westward of Ireland Island. The causeway flats are literally packed with coralline Algæ.

To the northwest of Western Blue Cut there is a stretch of coral covered ledges, which, like the ledges to the north and east of a line running west of Ireland Island, are somewhat isolated, and have remained disconnected from other ledge flats. They have not, like the Devil's Flat, and those to the westward and southwestward of them, been pounded and ground up to form coarse sand ledge flats with steep slopes, from the surface of which scattered æolian ledges barely project high enough to allow a scanty growth of Millepores and Gorgonians.

On the inner side of the reef massive corals do not as a rule seem to exist beyond four to six fathoms, the point at which the great expanses of coralline bottom begin, and which extend nearly unbroken to the greatest depths of the inner waters on the banks.

The greatest width of the belt in which corals grow from the inner edge of these flats or patches to the outer six or seven fathom limit is about three miles at the eastern extremity. This is nearly the width of the land and water belt included between the island of St. George and the entrance to Castle Harbor. The belt between Ireland Island and Gibbs Hill is however considerably wider than any of the ledge flats. At the western end it is not more than a mile, the ring of ledge flats being widest west of Mills Breakers, and diminishing towards North Rock. The ledge flats are much narrower along the whole western and southwestern face of the Bermudas. The gradual shelving slope of the ledges which have been abraded on the sea face of the flats is well seen between the entrance to Hogfish Cut and the Western Blue Cuts. The Little Bar and Chaddock Bar form two wide spits with a gradual slope from two to seven fathoms, covered by Gorgonians, Corals, Millepores, and Algæ. Long Bar is a similar ledge, separated however from the Western Ledge Flats by a channel of from six to seven fathoms, the bottom of which is covered with corals and the attendant Algæ and Sargassum. These bars are full of just such ledges as have been described, only they have been the first to feel the effect of the inroads of the sea upon the proto-Bermudian land, and have been abraded to a greater depth. We find on their slopes as much as four to eight fathoms as a general depth; the channels between the ledges are in most cases overgrown with coral and Algæ. Outside of the six or seven fathoms at which they still flourish, Gorgonians and Algæ extend on the broken ground down to a depth of seventeen to twenty fathoms, with here and there an irregular sandy patch between the ledges. In the channels between Long Bar and Little Bar and the Ledge Flats, which have a general depth of six to eight fathoms, corals and Gorgonians grow in patches which are separated by coarse bank sand. The same slope similarly overgrown extends to the Chub Cut, and from the Western Blue Cut it becomes narrower towards the Southern Ledge Flats.

On crossing the Ledge Flats opposite the southern end of Long Bar, one meets the same ledges, but more worn and covered by a larger number of massive corals and Gorgonians. In the channel between the Southwest Ledge Flats and Long Bar, which is itself made up of patches similar to those of the outer edge of the Southwest Ledge Flats, the heads and patches do not come so near the surface, they form patches of massive corals, Gorgonians, and Corallines, or Algæ separated by areas of clear, coarse bank sand bottom. Such is the character of the outer rim of the reef, wherever we examined it, to the westward of Hogfish Cut, beyond Chaddock Bar, outside of Chub Cut, to the west of the Blue Cuts, outside of North Rock Flats, and to the south of Mills Breaker and off the outer reef of the south shore. The ledge patches and coral heads increase rapidly in height and number as we approach the outer edge of the flats and Gorgonians, Corallines, and massive corals become more abundant also in the spaces between the patches. The bulk of the corals and Gorgonians do not seem to grow beyond ten to twelve fathoms; beyond that depth Gorgonians, Algæ, and Corallines preponderate, and cover the bottom.

Off High Point extend the Bream and Kitchen Flat Ledges. They are like all the other ledges of æolian rock, with more or less vertical honeycombed sides. On Chaddock Ledge there is a depth of two to five fathoms. It is, like Long and Little Bars, made up of ledges in somewhat deeper water. It is continuous with the flat ledges to the west of Hog Fish Cut, and not separated from them by a channel. On Chaddock Bar there is a fine growth of Gorgonians, of Corals, of Corallines, and of Algæ, which stop in from six to seven fathoms, where we pass into the broken ground described above. The bottom of the channel of Hogfish

Cut in eight fathoms, as it passes out on to the bank becomes hard, and is covered with Thalassia.

On the inner edge of the reef to the north of Three Hill Shoal, starting from Mills Breaker Passage, we could observe in the close network of ledge patches no differences between them and those of other localities. The massive corals are perhaps finer and more numerous than elsewhere on the reefs. The Mæandrinas and Astræans are more abundant, as well as the Gorgonians, Algæ, and Corallines. The submerged faces of the reef ledges, as examined through the water glass, show no difference from those of similar ledges, such as we see rising from six to seven fathoms of water to a depth of two or three fathoms at low water, on which corals, Gorgonians, Algæ, and Corallines have not as yet obtained a foothold. In the deeper parts of the interior sounds, in from ten or more fathoms (sixteen at the outside), the bottom sand is much coarser than we find it in the shallower patches somewhat protected by the reef ledges, or in the reef bights in which patches of sand run in a considerable distance between the ledges. The reef ledges close to the edge, with nearly vertical or very steep sides, in from ten to eleven fathoms, are often separated by deep passages covered with sand, though occasional patches of Gorgonians and Algæ or Corallines grow over this bottom, and form connecting bottom strips between the ledges. A considerable amount of dead material accumulates at the foot of the reef patches and ledge flats, and, according to its position, is being slowly ground into the characteristic bank sand bottom composed of fragments of Millepores, Corallines, Algæ, Gorgonians, and Nullipores.

The "breakers" known as special rocks on the outer edge of the reef flats, such as Southwest Breaker, the Mills Breaker, North and Northeast Breakers, and many others, of which the North Rock is the most prominent, are the remnants of islands and islets or of ranges of æolian hills which once rose upon the outer reef flats, and surrounded the now sunken sounds, the lagoons and waters of the inner part of the Bermudas to the northward of the islands. They have by most observers been considered as owing their origin entirely to the growth of the corals we find thriving upon the surface of the ledges which compose these patches.

There are also three or four breakers bare at low water between the North Rock and the Pilchard Dicks. The Southwest Breaker is the westernmost of a series of ledges parallel to the south shore extending to the eastward as far as the entrance to St. George Harbor, the æolian character of which can readily be observed. The inner ledges extending from the south shore reef towards the main island are the remnants of the platforms of rocks once rising above high-water mark, or forming perhaps small islands, rocks, and islets across the bays of the proto-Bermudian land. We find to-day such islands and rocks separating Castle Harbor from the sea, those across the mouth of St. George, or islands belonging to an outer line of ledges which may be entirely disconnected from land promontories, or form, as they do across Whale Bay, Sinky Bay, and parts of other bays, an outer barrier protecting the south shore somewhat from the beating of the surf till they have crumbled and in turn been reduced to ledges bare only at low-water mark. The true character of many of the ledges forming the flats or the connecting patches is hidden by the coral growth. But both on the north and on the south shore we can follow the passage of the æolian rock ledges as they recede from the shore, from nearly bare ledges still connected with the shore cliffs to the coral patches. The ledge at Briggs Flat is mainly covered with Gorgonians and Millepores. We find there but few heads of massive corals; they are small Mæandrinas and Astræans, together with an abundant growth of Sargassum, Algæ, and Sponges. The Sponges are more abundant on the connecting ledges, if I may so call the patches extending from the north side of the main channel towards the flats, than they are upon the outer ledge flats.

As far as we can judge from such an examination as can be made in crossing the reef flats from the inner waters to the open sea, in the sections across the reef at Hogfish Cut, across the Western Ledge Flats at Little Bar and opposite the west end of Long Bar off the Chub Heads, across Chub Cut, across the Blue Cuts, across at the Northwestern Ledge Flats, across at the North Rock, Northeast Flats, Mills Breaker Passage, and the main channel, all the "coral heads" or patches seem to be growing on the tops of pinnacles of æolian rocks, or of flat ledges, or of mushroom-shaped tables, or of large irregularly shaped ledges rising sometimes gradually in irregular shelving strata, or in nearly perpendicular steps, from six or seven fathoms of water to near the surface.

Passing through Chub Cut to the outside of the reef, we find in four to five fathoms large Mæandrinas, Astræans, and fine Gorgonians, together with the usual accompaniment of Millepores, Sargassum, Corallines, and other Algæ. As we pass into deeper water the massive corals become smaller; in seven fathoms they are quite small and not numerous, and the whole bottom becomes thickly covered with Gorgonians, Corallines, and Sargassum.

An examination of the charts of the Bermudas will show many places outside of the reef to a depth of twenty fathoms which are marked rocky (*r*). These spots are most probably the outcrops of æolian ledges of the proto-Bermudian hill lands projecting slightly above the sandy bank bottom and forming a part of the broken ground. Beyond that depth (twenty fathoms) the lead brings up what is called coral bottom, made up in great part of æolian sand and of fragments of Corallines, Algæ, and the like. There are also patches of this rocky bottom inside of the reef ledges, as for instance close to the Western Blue Cut, where all the hauls of the dredge only brought up small quantities of the bank sand bottom.

The bottom over the Bermuda Bank is quite uniform in character. The greater part of it is covered with æolian sand of different degrees of coarseness, and more or less mixed with fragments of coralline Algæ and of Millepores or Gorgonians.

In other localities the surface of the old æolian rocky ledges is exposed, and is comparatively bare of æolian sand, as in some of the sounds, and the bottom may be called rocky. On this Oculinæ grow in profusion in the deeper waters of the sounds, or the more massive corals where the sea has free access to the sounds.

To the westward of Wreck Hill there is a small extent of bottom in seven fathoms of water covered with very fine mud, much like the white marl off Andros. A similar patch of marl occurs to the eastward of Ireland Island.

## THE SERPULINE REEFS.

**Plates XXI. to XXVI.**

The serpuline reefs described by previous observers are perhaps the most interesting structures of the Bermudas. They are most numerous off the south shore, constituting miniature atolls and barrier and fringing reefs apparently formed by the upward growth of Serpulæ. While Serpulæ undoubtedly cover a great part of the surface of the structures, yet Algæ, Corallines, barnacles, mussels, and other invertebrates, are found to be fully as abundant as the Serpulæ, which in many cases play only a secondary part in the organic covering. In fact, it would be as correct in some localities to call them Algæ or Coralline atolls. Neither the Serpulæ nor the Algæ, nor any other organisms, have to any considerable extent built up the vertical walls of the different kinds of diminutive reefs so characteristic of the south shore. The

Serpulæ, Algæ, Corallines, and other growths have only protected the surface of the mushroom-shaped æolian rock ledges which form these structures from the action of the breakers. They have not built up the raised rims of the atolls, or the crescent-shaped or the horseshoe-shaped reefs, or the vertical walls forming the irregular convolutions and curves of the broader ledges.

Before my visit to the Bermudas I accepted the explanation given by older writers of the mode of formation of the atolls, as due to the accelerated growth of Serpulæ on their outer rim. I was therefore greatly surprised, on hammering at some of these structures, to find that the vertical walls were not built up, as is generally believed, of serpuline limestone, but were composed of æolian rock, and to discover that in many cases the elevated rim was protected by the hard ringing crust so characteristic of limestones exposed to the action of the sea, and further to find that the coating of Serpulæ, of Algæ, of Corallines, and of Nullipores was quite superficial.

Some of the serpuline atolls are circular and quite regular in outline, others crescent-shaped, while others are apparently formed by the accrescence of two or three atolls. Some of the circular atolls are symmetrical, with a central depression, at the bottom of which more or less sand has gathered. The rim of these atolls may project from a few inches to one and a half feet, or even more, from the nearly vertical base; its surface is completely covered by a thick growth of different species of Algæ, Zoanthidæ, Corallines, and Serpulæ. The rim varies greatly in width; in some cases it is not more than eight to ten inches, in others from one to five feet, and in some cases there is only a small circular pot-hole or a very circumscribed area left bare of growth in the centre. The rim is often greatly developed on the weather side, forming a crescent, tapering gradually to a thin wall on the opposite side. The crescent is often open for a great part of the circumference, the weak wall of rock forming its lee edge having been carried away by the breakers.

On the outer reef the ledges which are awash are similarly constructed. It is true there are few of the regular atoll shape, by far the greater number being long ledges of compound atolls made up of diminutive crescent-shaped reefs. Upon these ledges low vertical walls have been cut out varying from six to eighteen inches in height, following all sorts of curves, rising like a succession of **S**-shaped loops of circular or crescent shape, or re-entering curves, running in all possible ways, and which at first sight would appear to be all due to the growth of vegetable and animal life which covers the top and sides of the walls.

The Algæ, Serpulæ, Corallines, Mytilus, and the whole growth which goes to form the serpuline atolls, form but a thin coating upon the ledges of æolian material upon which they happen to have grown. Underlying this animal and vegetable coating we find the æolian rock, which on some parts of the ledge may still be protected by the hard ringing crust so characteristic of Bermudian and Bahamian limestone. The inner parts of the pool or atoll within the raised walls is composed of softer material, or of material which has not been protected by animal and vegetable growth from the destructive agency of the sea. The serpuline atolls are æolian rock ledges which once were a part of the south shore cliffs at the time when the shore line was farther to the southward and had not yet begun to yield to the inroads of the sea.

The protecting growth of the atoll has little to do with the formation of the wall forming the rim of the atoll; in some cases it has undoubtedly grown up perhaps twelve to eighteen inches above the wall itself, but the deep lagoons and steep vertical walls of the serpuline atolls so characteristic of the southern side of the islands have been formed, I believe, by the mechanical agency of the breakers. These diminutive atolls are large pot-holes excavated by the surf and sand, and the varied forms of circular or of crescent-shaped reefs, of barrier reefs, and all the possible modifications one finds on the south shore of the Bermudas, are primarily due to the mechanical action of the sea. All these structures, from a circular or elliptical atoll to a barrier or fringing reef, with all their possible modifications, are due to the action of the surf and the sea in wearing away the surface of the mushroom-shaped rock, which is either softer than the surrounding parts or is not protected by the covering coat of Algæ, Corallines, or Serpulæ.

One can off the south shore trace the whole process from the time when the large fragments of shore æolian rock fall by undermining into the sea, until they are changed by the action of the surf into mushroom-shaped ledges surmounted by pinnacles, and next into the stage when the pinnacle has in turn been undermined and dropped alongside of the ledge to become the holding ground of coral and other growths. The surface of the flat ledge which formed the base of the pinnacle is now freely acted upon by the breakers. According to the nature of the upper crust, and to the extent of protection given to it by the covering coat of animal and vegetable life, the sea acts upon it, and we have hollowed out diminutive circular atolls, crescent or horseshoe-shaped structures, as well as the curved, straight, or convoluted or looped vertical walls of broader ledges which stand up from the bottom and seem to have been built up by the organisms covering the surface.

The serpuline atolls are of all shapes, depending primarily upon that of the slab from which they happen to be formed. We may imagine one of the shore slabs or ledges more or less overgrown with Algæ and Serpulæ exposed to the action of the incessant breakers of the south shore. The sea face of the ledge either slopes rapidly or is more or less vertical, sometimes undercut or worn to a mushroom-shaped table. According to the hardness of the protected edge of the ledge or of its surface, it becomes more or less broken through by incipient pot-holes, which expose the softer æolian rock to the action of the sea. With each tide the wearing action increases, until a circular pool is formed, in which sand is constantly triturating and grinding away the softer surfaces. Thus a miniature inner lagoon becomes excavated, not more than a few feet in depth, and surrounded by a more or less regular rim; the depth of some of the shallower lagoons varies from twelve to fifteen inches. On a ledge in which a pot-hole has been formed the sea thus washes at first into a shallow dish, or into a series of dishes which are soon run together, and thus a straight or curved or **S**-shaped vertical wall may be excavated on the edge of a ledge of æolian rock, the inside depth in one case being eight feet.

The serpuline atolls take their greatest development towards the western part of the south shore. Off Great Turtle Bay we find the same extraordinary development of the serpuline atolls and reefs which we traced farther to the eastward, off Hungry Bay and off Elbow Bay. There is hardly a sunken ledge on or along or off the south shore of which the surface is not protected in some way by Algæ and Serpulæ, and covered with structures which are directly the result of the action of the sea upon the friable æolian rock of which the ledges are composed. It is indeed a remarkable sight to see, as far as the eye can reach in either direction, this narrow belt of ledges which have been so strangely modified by the action of the sea and the protecting agency of the animal and vegetable growth upon its surface.

The presence on the south shore of so many striking circular atolls and horseshoe-shaped, crescent, or curved rings, or partial rings, and **S**-shaped walls, withdraws the attention from the far greater number of mushroom-shaped blocks and ledges which no longer reach the surface, owing to the wearing of the æolian rock of which they are composed. The atoll-shaped ledges have attracted more notice, not on account of their greater number, but mainly from the interest centring in such structures. For alongside the atolls, either rising to the surface, or near to it, or always covered at low water, there are other ledges, of endless differing shapes, which do not attract the eye, but which play as important a part in the economy of the ledges off the south shore as the atoll-shaped structures themselves, and which give us the clue to their formation.

Everywhere on the shores of the Bermudas where active degradation of the coast is going on we meet with a number of ledges, or pinnacles, or islets, or mushroom-shaped rocks, which have been fashioned by the sea into a nearly circular or elliptical form. Sometimes a number of these isolated rocks may stand in a row above high-water mark, the stems almost eaten away from the ledge upon which they stand. When the top tumbles over, the support, or a part of it, may remain well above low-water mark. It is upon these ledges of all sizes, from a foot or so in diameter to long elliptical or irregularly shaped masses of fifty to seventy feet in length, or even more, that the sea begins to act, and to shape the serpuline atolls of the south coast, though they are not confined to it, as I shall show hereafter. Standing on some parts of Elbow Beach, one may follow the irregular mushroom-shaped rock ledges standing between high and low water mark to those at and beyond that point into deeper water. We may note the changes which gradually take place as the protective growth upon these irregular ledges, at first bare, transforms them into the atolls, or crescent-shaped or **S**-shaped structures forming the reef off the south shore. One can watch at low tide and see the breakers combing in over the rim of the little atoll scouring the lagoon, and the superfluous water flowing over its sides. The sea breaks over the edge, carries off such loose fragments as may have been started by the preceding rollers, and scours the inside with the sand it may have brought in, in addition to what it finds inside.

Some of the crescent-shaped serpuline reefs are formed on ledges bare at low water extending out from shore. They form low vertical walls of from twelve to twenty-four inches in height, running in a series of irregular curves, a kind of festoon as it were, protecting the inner lagoon or lagoons of all sizes and shapes which have been gouged out by the waves. It is not uncommon on the south shore to find fine sand deposited on the flat ledges near low-water mark, and kept in place by the growth of a thin sward of Algæ; this, together with the thin crust formed over its surface, hardens the mass, keeps it in place, and enables it to resist the moderate action of the breakers.

Going westward from Great Turtle Bay to Warwick Bay we find the same condition of things, — an outer ledge of boilers together with irregular inner rows of ledges running close to the line of low-water mark, and gradually passing into the mushroom-shaped ledges which still form a part of the shore cliffs.

The district extending from Sinky Bay west and east is specially instructive, as showing the method of irruption of the sea through low shore cliffs to form small boat bays, and the gradual passage of these shore cliffs to lines of rocks and islets running parallel to the coast, and cutting out such bays as Whale Bay, Bailey Bay, Warwick Bay, Great Turtle Bay, etc. We may next follow the passage of these cliffs to submerged ledges, and their transformation into the boilers off the south shore and the outer line of boilers forming the so called reef off the south shore. The most striking of the serpuline reefs are the fringing and barrier reefs, and their outlying atolls, off one of the points at the east end of Whale Bay, together with the lines of atolls and variously shaped serpuline reefs extending to the eastward. Nowhere perhaps on the south shore do we see so clearly the transition of the isolated mushroom rock ledges surmounted by æolian pinnacles into the ledges which are to become serpuline reefs, as in the district between Great Turtle Bay and the bay at the foot of Gibbs Lighthouse.

From the descriptions given above of such a variety of reefs formed by the serpuline ledges, and of the action of the sea upon them, we may obtain on a small scale an illustration of the mechanical theory of the formation of some coral reefs. This may be specially applicable to the formation of compound atolls, as has already been suggested. We find off the south shore, in the same area and subject to identical conditions, patches which assume the shape of atolls of fringing or barrier reefs all within a stone's throw of one another. But in this case the structure of the foundation gives us the explanation of their formation, for the shape of these diminutive reefs is primarily determined by that of the ledge, and not by the growth of the Serpulæ. The different shapes of these diminutive reefs can be traced to the manner in which the sea has acted upon their æolian substructure. It may have only honeycombed the surface of a large cliff fragment, and left it as it fell, merely covering its diminutive spires and hollows with a thin layer of Serpulæ, Mytilus, Algæ, and Corallines. It may have washed off from the shore cliffs slabs of æolian rock in such a manner that as they lie on the beach the strata are horizontal, and, the edges having become cemented by the action of the sea, the division lines become obliterated, and over their surface has grown an animal and vegetable covering. It is not an uncommon thing to see on some of the beaches large slabs of base rock, upon the hard ringing surface of which grow Algæ; these collect particles of sand, and thus form a coating from a quarter to three quarters of an inch thick, upon which larger Algæ then flourish. In the intermediate spaces grow the Serpulæ, Mytilus, and Corallines, which soon conceal the surface of the ledge by their protecting coat. Should this slab alone or with adjoining slabs form an extensive ledge far enough out from the beach to be exposed to the action of the breakers, its nearly vertical sides would form a rampart over which the sea combs and pounds down over the edge of the slab, striking beyond the outer edge well toward its interior, according to the size of the breaker. If there exist at the points reached by the breakers any weak spot in the protecting crust, or any incipient fracture, or any difference in the hardness of the upper layer, the sea soon makes an inroad upon it. It grinds out the softer interior parts, which are carried off, and thus forms the beginning of a flat shallow saucer-shaped cup on the inner part of the ledge. The outer rim, on the contrary, protected either by a hard crust or by a growth of Algæ and of Serpulæ, remains intact, and gradually rises higher and higher, partly from the additional growth of the Serpulæ and other calcareous organisms, but mainly by the grinding away of the interior of the ledge to form a basin, which little by little becomes deeper. The organic growth on the outer rim is more vigorous than in the basin itself, either on its sides or on the bottom, where the sea breaks and is at work grinding away the protecting growth. The Algæ, Serpulæ, and other growths become less abundant in proportion to their distance from the outer weather rim, until, towards the centre of the atoll, the inner ring or cup or slope is covered with sand. We thus have diminutive atolls, barrier reefs, or crescent-shaped or horseshoe-shaped structures formed out of the æolian rocky ledges. Should the sea face of the slab be harder than the faces of the sides or of the leeward side, some of those strata are soon broken through, and gaps made in the rim, forming a crescent-shaped wall or arc with its greatest height seaward, the wall gradually falling to leeward to the level of the ledge, and the raised edge sloping towards the horns of the crescent on either side. The lee face of the crescent-shaped atoll is in such a case thoroughly scoured by the outward rush of the sea, which, carrying with it a certain quantity of the sand that fills the depression, runs off the lower lee side with considerable velocity. The depth of the atolls varies from a few inches to six feet or more. The lee faces of both horseshoe-shaped and crescent-shaped atolls are frequently so rapidly removed as to leave nothing but a vertical wall of from one to two feet on the weather face of the ledge.

The diminutive reefs formed off the south shore of Bermuda are of all possible shapes, — atolls with regular rims of the same width on all sides, atolls with the sea face rim wider than that to the leeward, and parts of rims of circular atolls of horseshoe or crescent shape, or only of parts of arcs of greater or less extent. We also find belts of small atolls on ledges of considerable width, and atolls of an elongate type; others are dumbbell-shaped, formed evidently by the breaking through of division walls of circular atolls. We also meet with chains of atolls, each one forming a link as it were, or irregular parallel chains, which, when the separating walls are broken through, give the elements for all the possible figures assumed by the ledges off the south shore. When such reefs are formed on the shore ledges, we have all the possible types of fringing and barrier reefs, or combinations of these, forming diminutive reefs with low vertical walls apparently most irregularly placed, often as if their existence in their varying shapes and positions could be due only to the upward growth of the Serpulæ and Algæ. But I believe that the vertical growth of Serpulæ and Algæ is not of itself sufficient to account for the existence of the vertical walls, and that they are due only in small part to the upward growth of organic material, and in a great measure to the action of the breakers upon the æolian rock ledges, probably in the manner I have just described.

The barrier reef off the small spits to the east of Whale Bay at the Targets may be described as a vertical wall surrounding three sides of a rectangle, the diagonal of which is somewhat over fifty feet; the sea face corners are well rounded and the side walls formed of short arcs. The distance from the shore edge of the ledge to the outer wall is about twenty-two feet. The greatest width of the rim is at the two outer angles, where it varies from five to six feet; the inside edge of the sides of the rim gradually passes into the shore ledge, being in a general way parallel to the trend of the sides of the barrier reef. The raised part of the rim varies from twelve to sixteen inches in height. The outer vertical wall has a height on the west of eight feet, and on the east of about six feet, the slope of the ledge being more or less concentric round the deepest part as a centre, and sloping sideways towards the shore edge. The outer rim at two points is gouged out into two smaller elongated pits. The rim is everywhere well protected by Algæ, Corallines, and Serpulæ, the Algæ growing on the more or less level platform of the rim, and on the outer and inner faces of the vertical walls of the barrier reef. The ledge is greatly undercut, and its outer faces present all the irregularities of wear by water so characteristic of shore ledges. The inner slope is covered by a thin growth of Corallines and smaller Algæ, which do not seem to thrive as well as where they receive the direct force of the breakers. Close to the westward of this diminutive barrier reef are ledges which may be regarded as typical of the changes which have taken place in a bare æolian ledge just dropped from the shore cliffs until it becomes a typical boiler of the south shore. One of these is separated from the western edge of the barrier reef by not more than six feet, and has a depth of water of more than ten feet in the passage between them. To one side of this dumbbell-shaped atoll, which is nearly thirteen feet on its longest axis, is another atoll on a mushroom-shaped ledge seven feet in diameter, with a regular rim and a pot-hole of three feet in depth. This is separated from the adjoining mushroom-shaped ledge by a gap of four feet, with a greatest depth of ten feet, and eight feet on the shore edge; it is separated from the shore and a large ledge to the south by a deep passage of nine feet in width. The length of the larger ledge, irregularly shaped, is over forty feet, and its width varies from twenty to thirty-five feet. Its outline is formed by curved walls, the edges of irregularly shaped elongated or circular dumbbell-shaped pits gouged out from a broad platform of æolian rock. On the lee part of the ledge an irregular rectangular pot-hole has been formed, five feet in depth on one side and four on the other, sloping upward toward the broad outer rim. Comparatively slight variations would change the surface of the ledge into an atoll with a narrow rim following the outlines of the ledge; or it may become divided into two irregularly shaped pits by the coalescence of the few smaller pits now upon the platform, and a single curved wall, the remnant of the face of one of the circular pits, would form a division wall; or the sea may break through to a greater extent than it has done already and leave on this ledge only disconnected fragments of wall of varying shape, in which it would be difficult to recognize the walls once limiting circular or dumbbell-shaped pits. Outside of the larger ledge is a pear-shaped atoll with a broad sea face or rim sloping inward, and a circular pot-hole about three feet in depth, the rim of which is narrower to the leeward.

All these ledges are deeply undercut and abraded, and are mushroom-shaped; their faces are vertical or nearly so, and all show traces of the action of the sea upon the pillar forming the base. The ledges I have examined close to the shore, half-way to the reef, or on the outer line of ledges, all present modifications of the ledges described. Their ultimate shape depends upon many local factors, and they show but a small number of the possible intricate figures that are found on the æolian ledges off the south shore. The Algæ, Serpulæ, and other organic growths which thrive upon the edges of the ledges and spread down upon the vertical faces, still further protect the sides of the mushroom tables from being washed or eaten away by the forward and backward rush of the sea.

Off the same locality an elliptical atoll forty by thirty feet, standing in a depth of ten feet at low water, formed the spreading top of a mushroom-shaped ledge from the vertical sides of which all traces of the æolian character of the substructure had disappeared. Where not overgrown with Algæ and Corallines, it showed the peculiar gouging out and honeycombing character of all shore rocks, either when exposed at low water or where extending below it. The inner part of the weather rim was not quite parallel with the outer outline; it projected in the centre and was somewhat scalloped in outline, with a few small deep pits. The rim varied in width from five and a half feet on the weather side to one foot in its narrowest part on the leeward edge. I could not detect that the weather rim was perceptibly higher than the leeward rim, though this is not unfrequently the case.[1] The pot-hole was six feet in depth nearer the western edge, gradually decreasing in depth to three feet on the opposite side. A crescent-shaped lagoon eighteen feet in diameter, greatly undercut, especially on the weather side, as all these ledges are, had a rim five feet wide at its widest part, gradually tapering to four or five inches at the two extremities of the crescent. Both this and the elliptical atoll just described had a narrow shelving platform on the inside of the weather rim. The lee edge of this crescent-shaped atoll was worn away five feet lower than the weather rim. A circular atoll twenty-five feet in diameter was surrounded by an irregularly elliptical rim twice as wide on the weather as on the lee side, forming a scalloped pot-hole with a greatest depth of three feet. Along the south shore I observed a great number of ledges with nearly flat tops, from which the surmounting æolian pinnacles had been worn away; some of them were just awash at low-water mark, others reached half-tide mark, and a great number were sunken ledges. On these last, if forming the inner part of the outer line of ledges, are found Gorgonians and corals, giving them to a certain extent the appearance of a coral reef.

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[1] Heilprin speaks of the Serpulæ as occurring "in dense bunches," and where the surf beats hardest "the Serpula growth was most largely developed, and to such an extent as to form a raised rim or barrier to the more protected inner side." But, as he himself says, (and I am not quite clear whether he attributes the formation of the atoll to the Serpulæ,) "the breaking in on all sides of the surf has created a number of more or less irregularly oval islets with depressed centres, or, more properly, with elevated borders." In the one case he says, "The depression is merely a negative one, being such by reason of a somewhat more rapid growth developed only from the water line, or within the surf," but he feels satisfied, however, that the two structures (these serpuline atolls and the coral atolls), while seemingly alike, have practically little or nothing in common.

Off White Cliff Bay there is an excellent specimen of an irregular crescent-shaped barrier reef formed upon a ledge barely in contact with the beach at low water. The wall on the inside is formed of short irregular steps, and the inner area of the ledge is thickly overgrown with calcareous Algæ, more or less covered with æolian sand washed from the friable parts of the ledge.

The narrow pedestals which are the bases of some of the pinnacles of æolian rock are often the remains of extensive flat ledges on which the different organic growths characteristic of boilers have obtained a foothold. The parts of the tops and sides of these ledges which have not as yet been covered by such a growth, or only partially so, plainly show that they differ in no way except in size from the smaller mushroom-shaped æolian rock ledges, and are formed by the same agencies. The larger pinnacles of æolian rock like those still standing off Whale Bay will become, when they fall, large flat ledges upon which the sea when breaking digs out irregular pot-holes of all shapes and sizes. The remnant of the base of the pinnacle becomes, when worn away by the sea, either a shelf or a flat corrugated ledge, and the more or less vertical sides below low-water mark are worn away by the wash of the sea into mushroom-shaped ledges.

At the east end of Elbow Beach several patches of honeycombed shore rock ledges have been left stranded in the midst of the beach sand surrounding them. These ledges, if exposed to the action of the sea, would soon be worn flat, and according to the angle of their stratification would be dug out into atolls or other irregularly shaped structures protected by Algæ and Serpulæ. The same serpuline growths and similar convoluted walls occur on the North Rock and the adjoining ledges on the north. Similar structures, forming more or less distinct reefs, also occur off the north shore and elsewhere on the edge of the reef flats, but they are not as numerous nor so well defined as a rule. They consist, however, always of the same mushroom-shaped ledges, sometimes still surmounted by their pinnacles of æolian rock, and of others abraded to the level of low-water mark, or even well below it. The shore ledges on the south coast are acted upon by short, sharp breakers, formed in from one and a half to two fathoms of water, beating upon the ledges much as a small waterfall drops upon the rocks at its base. On the north shore the breakers and sea do not act with the same regularity as on the south shore. There, owing to the existence of an outer line of reefs, the conditions are more uniform than on the north shore, where the effect of the winds upon a comparatively broad stretch of sea are far more variable.

On the north shore the surface of the ledges between high and low water mark is protected mainly by a small species of barnacle, clusters of small Mytilus and incrusting Nullipores, and a few species of small Algæ. At or below low-water mark Sargassum begins. Serpulæ are not as common as on the ledges off the south shore. On the north shore serpuline atolls are most numerous on the ledges off Spanish Point in an easterly direction for a distance of four or five miles.

The mode of formation of the peculiar and intricate windings of the vertical walls which crop up to the surface on the summits of the ledges, and which take on such complicated curves can readily be explained from the manner in which the ledges themselves yield to the action of the surf from the wash of the sea, and also from the angle at which the æolian strata lie when attacked by the waves.

The following diagrams will further explain the mode of formation of the various serpuline reef structures which have been described.

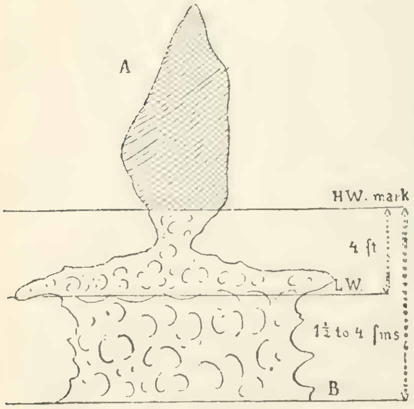
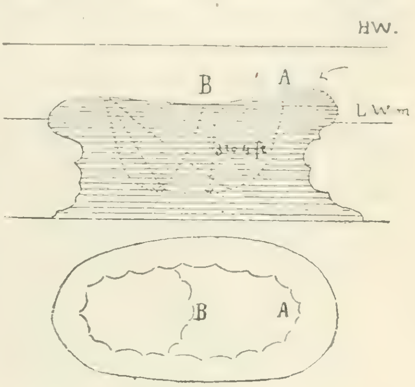
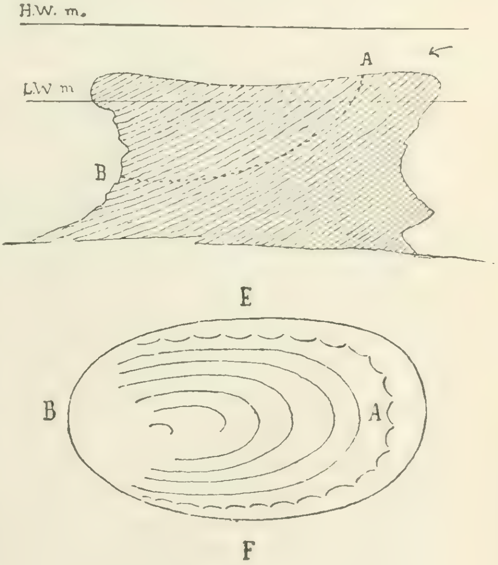


Fig. 1.

AB (Fig. 1) is a piece of shore cliff which has become isolated from the shore; the æolian lamination is clearly seen above high-water mark. Below high-water mark it is honeycombed and eaten away, leaving the æolian pinnacle supported only by a slender stem rising from an extensive base more or less covered with Algæ, Serpulæ, and other growths. The surface of the ledge, as well as the base of the mass extending below low-water mark, is more or less eaten away, and when the æolian pinnacle (A) has fallen off a mushroom-shaped mass is left, the upper surface of which may be above or below low-water mark. All trace of æolian stratification has been obliterated by the cementing and solvent action of the sea water. If the base, the mushroom-shaped ledge, is stratified horizontally (Fig. 2) the result of the wash of the breakers upon any part of the top left unprotected will be to dig out circular or elliptical atolls (Fig. 3) like A or B. In one case, A, the atoll will have a rim of nearly the same width, while in the other case, B, if the softer parts of the top are on the lee side, the atoll will have a wider rim on the weather side from B to A, or a pot-hole may also be formed between A and B. The pot-holes of these circular atolls are usually from three to four feet in depth. But in some cases I have measured them between five and six feet, and even more. In others they are only a few inches deep. I have not observed any growth of Serpulæ of greater thickness than from twelve to eighteen inches.



Figs. 2, 3.



Figs. 4, 5.

Should the æolian strata dip towards the lee side (Fig. 4) a horse-shoe-shaped atoll is formed, as indicated by the dotted line AB. The rim is widest at A, Fig. 5, gradually becoming narrower and lower towards the lee side as it nears B, the whole or the greater part of the ledge having been carried away by the pounding of the surf, leaving a high narrow wall with a deep opening at B between its extremities. Should the surf break through the sides at E or F, or both, we should have curved vertical walls left, apparently built up by Serpulæ, in reality walls of æolian rock which may be dug out as I have suggested, either in the case of Figure 2 or of Figure 4.

When the pinnacle finally drops off, it will in its turn be attacked by the sea, and go either to form a smooth ledge, to be covered with Algæ and Serpulæ according to the depth in which it lies, or may in its turn be attacked in a similar way to the ledge, and changed to an atoll or a crescent-shaped serpuline reef according to the dip of the strata. Before the breaking off of the pinnacle, Algæ and Serpulæ have already begun to grow upon the flat part of the ledge, and protect it to a great extent from the action of the sea. When the sea no longer washes round the pinnacle, but breaks on the ledge at low water, and finds a part which is not protected by Algæ or otherwise, it begins to erode it, the sand formed acting like a churn, and thus little by little forming a deep hole in the centre of the mushroom rock.

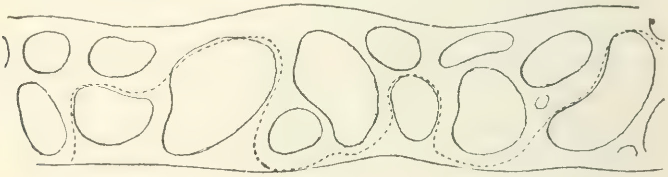


Fig. 6.

In the case of a long and wide ledge, there are formed upon it a number of secondary pits and atolls, or pot-holes, as indicated by the heavy lines of Figure 6. Let the walls of these break through and connect adjoining pot-holes and we obtain a vertical wall, of irregular outline, such as is indicated by the dotted line of the figure, which is a diagram of one of the ledges of the outer reef off the south shore. The wash of the sea may break through the continuous wall, leaving only disconnected parts standing, or we may have the outer walls on the edge of the ledge left, forming a long trough.

A flat ledge projecting from the base of a shore cliff, if eaten into in the same way by the surf (Fig. 7), may be worn into a circular reef with vertical walls, of which the top is protected by Algæ and Corallines or Serpulæ, with a pot-hole near its outer wall, in this case eight feet deep. We might call this a diminutive barrier reef. If the walls are parts of diminutive barrier reefs, the shore cliff behind them may disappear, and thus leave a wall standing apparently isolated from the level of the ledge. It is not surprising that a cursory examination of these walls and atolls should have induced the earlier observers to attribute the growth to Serpulæ.

Rice accepts the theory that the serpuline reefs are due alone to the upward growth of Serpulæ. He has also observed the circular ridges of coral on the outer ledges (Millepores) similar to the serpuline reefs, except that they are less elevated, their upward growth being limited by the inability of the corals to survive an exposure above the water. These circular reefs are either serpuline or edged by Millepores, and are called boilers; off the south shore they are generally serpuline, with only here and there a Millepore boiler on the inner patches. Along the east shore of Harrington Sound there are a number of such Millepore atolls and barrier reefs which are merely rims of pot-holes protected by a growth of Millepores. A number of these Millepore reefs extend eastward on the northern side of the main channel off Spanish Point. Along the shores of Harrington Sound we meet occasionally one of the vertical walls or irregularly shaped pot-holes of a projecting ledge, the top of which is protected by a growth of Millepores, much as the Serpulæ and Algæ protect the walls of the pot-holes off the south shore. On many of the patches to the north of the main channel, in a line from Ireland Island to St. George, we find a similar growth of Millepores protecting the exposed ridges of æolian rocks. Thomson also considers the serpuline reefs as due to the agency of Serpulæ.

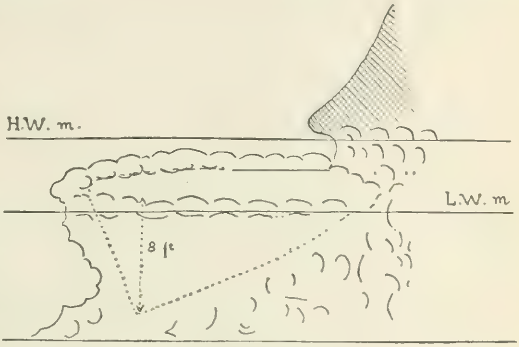


FIG. 7.

The existence of such a variety of reef forms under the same conditions naturally suggests whether the explanation by mechanical causes, such as finds here its application on a small scale for serpuline reefs, may not be a natural explanation also of the formation of the complicated systems of atolls of the Carolines, Marquesas, and Maldives, and whether small simple atolls like the typical ones of the Pacific, and many with complicated outlines, may not in many cases be due to the scouring action of the sea working on a larger scale upon substructures easily yielding to its effects. When examining the Hogsty Atoll of the Bahamas I could not fail to be struck by the overpowering mechanical force incessantly at work. Huge breakers were constantly pouring an immense volume of water over the windward sea face of the atoll, filling its cup to overflowing, and it could find no outlet except over those parts of the sides which were lower than the windward face, or through which, near the lee ends, passages of considerable depth had been eroded, or, finally, through the still deeper channel between the lee extremities of the reefs forming the entrance to the atoll. That is, given a bank of suitable depth upon which corals can flourish, and upon a belt of a certain width, they will form a protective coating to the underlying rocks, just as the serpuline growths protect the rims of their diminutive atolls. Corals will naturally, from the centrifugal action of the sea, grow on the outer faces, and most abundantly in the direction in which they find least resistance in the way of detritus and other accumulations. The sea breaking over them will excavate a lagoon, and break through the sides or lee face to allow the water to flow out through the points of least resistance, and through the entrances to the lagoon. All these causes are important factors in any theory of coral reefs, and show the complexity of the problem, and the impossibility of framing a single hypothesis to explain the formation of coral reefs in all parts of the world.

Before seeing the serpuline atolls of the Bermudas it had occurred to me that the configuration of the Hogsty Reef and the formation of its atoll might be due to mechanical causes. We may imagine a bank of the proper depth, whether formed during subsidence or elevation is immaterial, on which corals begin to grow and form a barrier to the surf. The breaking of the surf over this living and protecting barrier digs out the least resisting portions of the surface of the bank, and the material thus dug out finds its way out on the opposite side. Little by little a lee channel is thus formed by the scouring of the mass of water poured over the reef into the incipient lagoon, and a lagoon may be formed on a large scale in the manner described for the formation of the serpuline lagoons of the Bermudas. We may imagine the Hogsty Reef at one time to have been a bank formed by a series of small, low æolian hills, which have been worn away and have disappeared from the same causes which acted on a larger scale at the Bahamas. The Hogsty Bank was thus brought by subsidence and erosion to its present level, or nearly so, after the growth of a barrier of reefs on the remnants of the æolian hill ledges, then began the action of the surf in eating away the central part of the bank, scouring the lagoon to the depth and dimensions it has now attained. There is nothing to show that the depth of the lagoon of Hogsty Reef is due to subsidence, or that the rate of growth of the reef was synchronous with it, and thus formed the outer rim of the lagoon. On the contrary, judging by analogy and by the conditions existing in the Bahamas and Bermudas, we are led to infer that the lagoon of Hogsty has been formed by a mechanical process, that it is due to the action of the surf acting as an immense force pump driving the water over the weather face of the reef[1] out through the lee opening of the lagoon, or the openings of the sides of the ring, much as the diminutive serpuline atolls and crescent-shaped reefs or barrier reefs have been formed off the south shore of the Bermudas.

## POT-HOLES.

**Plates XXIX., XXX.**

Roots and stems, after being decomposed, may form branching cavities which if filled with stalagmitic matter would give rise to columnar structures. Such formations can be traced in the more recent dunes of the Bahamas and Bermudas, and of the Sandwich Islands. There is a type of pot-hole which imitates these structures[2] and has been confounded with the branched bodies, but which I do not believe to be organic structures at all.[3] They are the so called palmetto stumps, of which Rice has given an excellent description,[4] and which I imagine to be mechanical structures of a similar origin with the serpuline reefs (Plate XXX.).

To the north of the Devil's Hole, on the road skirting the east shore of Harrington Sound, we find a flat ledge of æolian rocks which is literally riddled with pot-holes, many of which have become connected to form dumbbell-shaped cavities or other irregular forms (Plate XXIX.). They are in every respect similar to the serpuline atoll pot-holes off the south shore, but are much smaller, and become changed many of them into the so called palmetto bases.

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[1] That water falling from a small height does thus excavate deep holes at the foot of falls is well known. Any country ditch dammed by a sluiceway will show this effect. It can be seen at the foot of every waterfall, and it occurs on the largest scale in the Mississippi, where the scour of the river below New Orleans has since the building of the jetties excavated a depth of between sixty and seventy feet in some cases, — a depth about the same as that of many lagoons of coral atolls.

[2] I cannot agree with Thomson (Atlantic, I. 330) in his explanation of the mode of formation of the pseudo palm stems, who considers them to have been formed on the bottom of caves by the dropping of stalagmite, and thus forming a single or double or dumbbell-shaped stem.

[3] Are not some of the tubes to which Professor Dolley ascribes a vegetable origin merely small pot-holes such as I have figured on Plate XXIX.?

[4] Bulletin of the National Museum, No. 25, p. 27.

An irregularly shaped pot-hole with a raised rim is one of the prominent features of one of the ledges on the north side of the causeway leading to St. George. In this case the greater hardness of the rim has formed the protective coat for the low vertical wall of the pot-hole (atoll). The transformation is readily followed in the pot-holes which are a little removed from the immediate action of the diminutive, but short and sharp, breakers of Harrington Sound. The inner cavity of the pot-holes becomes lined with a harder coating, being acted upon much as is the surface of the æolian rock. When the walls of adjacent pot-holes are eaten away or worn away by the action of the rains and of the sea, there may be formed an outer coating from the adjoining pot-hole, and thus an irregular cylinder will be left standing above the surrounding area. If the upper part of this is in turn disintegrated, we may have left a deep cup, or merely a ring of the base, or a side of the cylinder, or merely the harder inner coat of the bottom, — all of which stages resemble more or less the base of a palmetto (Plate XXX.). These pot-holes are often so close together (Plate XXIX.) that it is difficult to imagine a grove of palmettos the stems of which could be packed in the area occupied by the pot-holes. Captain Carr, R. N., called my attention to a locality on the east shore of Ireland Island where these pot-holes are numerous, and where one can trace all the transition stages just described from the pot-holes of the shore of Harrington Sound.

## NORTH ROCK.

### Plate VIII.

The North Rock is undoubtedly the most interesting monument left of the former extension of the Bermudian land. Owing to the difficulty of landing, it has not been visited frequently, but we were twice successful in landing at the North Rock Ledge.

Excellent descriptions of the North Rock pinnacles and ledges have been given by Rice,[1] and also by Heilprin in his volume on the Bermudas.

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[1] Bulletin of the National Museum, No. 25, p. 14.

The flat ledge surrounding North Rock presents no features different from those of similar ledges off the south or north shore. Its surface rises here and there in low ridges, which are the remnants of the last pinnacles to be eroded; near the edges, and wherever the action of the breakers reaches, it has been dug into so as to form pools, pits, and potholes of various depths and shapes, and has been honeycombed in all directions, according to the quality and hardness of the rock and the extent of the protection afforded the rock surfaces by the growth of Algæ, Corallines, Serpulæ, and other organisms.

The North Rock Ledge is deeply undercut, and, like many of the larger islets off the main island, its sides are more or less vertical, or steep slopes deeply honeycombed and cavernous, and overgrown with Algæ, Corallines, Gorgonians, Millepores, and massive corals, much as any similar ledge or cliff or patch. The greater part of its upper surface is protected by the hard ringing æolian rock characteristic of the exposed intertidal spaces. The pinnacles which remain rising above the general level consist of æolian rock, and the lower base rock seemed to me to differ in no way from similar æolian rock as modified by the action of the sea in other localities. It is possible that the fossil Cypræas stated by Rein to have been found at the base of the pinnacles may be only such shells as have been collected from the serpuline rock in which they had become embedded. In some spots on the ledge it attains a thickness of from twelve to fifteen inches, and is full of boring Mollusks and of shells which have found a foothold in the cavities of the honeycombed rock. The serpuline rock itself often becomes quite hard, and might easily be mistaken for true hard ringing æolian rock, but is readily distinguished from it by the presence of the many sharp pinkish fragments of the tubes of Serpulæ.

The many Chamas and other Mollusks living on the edge of the North Rock Ledge at low-water mark would, if thrown up and embedded in æolian or serpuline rocks, present all the characters of the so called fossils found in the æolian rocks of the islands of Hamilton Harbor. At Agers Island and on the shores of the other islands of Hamilton Harbor we find at very low tides many specimens of Chama which would have to be carried but little way to become æolian fossils. Neither Heilprin nor myself found any fossils on North Rock. Heilprin considers the lower portion of the North Rock pinnacles to be unquestionably pits and potholes of the inner surface of the beach rock.

The outer edge of the northeastern part of the ledge is protected by Serpulæ, Algæ, and Corallines, forming low vertical walls as well as the division walls of the irregular pot-holes of the ledge, and in places they overhang to a very considerable extent. The coating of Algæ and of Serpulæ on some of the walls of the interior pools is quite thin, as upon breaking off the edges we came upon the ringing æolian rock. On the northeast edge of the ledge a deeper pot-hole has formed a regular barrier reef, the edges of which are covered by Serpulæ, Algæ, and Corallines. On the interior of the ledge their growth is less vigorous. Outside of North Rock there are a few ledges, both to the southwest and to the northeast. Those towards the inner side of the reef are the outer reef patches, on which grow Millepores, Gorgonians, and the usual growth of corals, Algæ, and Corallines, which have completely hidden the nature of the ledges. The ledges which form the continuation of North Rock to the east and west, on the contrary, still plainly show that their structure in no way differs from that of the North Rock Ledge. Outside of North Rock "broken ground" extends to ten or twelve fathoms, but no patches of corals could be seen beyond five or six fathoms. We might call the outer ledges of the reef near North Rock a flat of coral heads and of Gorgonians. On the North Rock Ledge flat, Zoanthus, Millepores, Algæ, and Corallines are most flourishing.

Winding our way towards St. George Island from the North Rock, we picked our passage between the many mushroom-shaped ledges. Many of them came to the surface or nearly so, and on two of the ledge patches rather nearer the inner line of the ledge flats than to the North Rock I broke off a piece of hard ringing æolian rock in every respect similar to that of the North Rock Ledge flats.

We could not have a better example of the true nature of the reef ledge flats and patches than is exhibited by the North Rock Ledge and the adjoining patches. Those of the ledges nearest to the North Rock show the hard ringing æolian rock which marks the North Rock Ledge; some of the patches are separated from it by water five to ten fathoms deep.

We can easily imagine the whole of the ledge flats of the vicinity to have been made up of æolian rock ledges and pinnacles, very much like those off the north shore, on which corals, Gorgonians, and the like have little by little become attached, and have finally grown over not only the sides, but the upper surface after it became eaten away well below low-water mark.

There may have been on the northern reef flat ledges lower lines of hills than those now existing on the Bermudas, or low hills like those separating St. George and Castle Harbor, or along the west end of St. George Island and on the north side of Harrington Sound.

## PROTO-BERMUDA.

### Plate II.

Rein, Thomson, Rice, Fewkes, and Heilprin, all agree to the former greater extension of the Bermudian land, and Thomson,[1] speaking of the North Rock, and of Pulpit Rock off Ireland Island, says there can scarcely be any doubt that the dry land of Bermuda at one time occupied a space considerably larger than it does at present.

We may readily reconstruct the proto-Bermudian land from the existing charts (Plate II.). Beginning with the line and clusters of islands running from Ireland Island to St. David Head, these must in earlier times have been somewhat wider. The main island must have extended south beyond the line of the reef, and dry land must have completely barred the access of the sea to the sinks which on the east constituted Harrington Sound and Castle and St. George Harbors, St. George Island itself probably forming the western edge of the Ship Channel valley. On the west the main island reached to Hogfish Cut valley, and Somerset and Ireland Islands were probably connected with a range of æolian hills running from Chub Cut across Elies Flat. On the east, Ireland Island was connected with Spanish Point by a ridge which isolated Great Sound, Port Royal Bay, and Hamilton Harbor sinks from the outer lagoons, Great Sound and Hamilton Harbor both probably being disconnected sinks, and both isolated by low saddles from Great Sound sink. The ledge flats to the west of Hogfish Cut and to the north of Chaddock, Little, and Long Bars, which pass to the east of Chub Heads as far as Chub Cut, formed, in connection with the Elies Flat, hills of which the ledges are the remnants, the barrier separating a great sound larger than any now existing from the adjoining proto-Bermudian sounds. Of these we can trace four others of great size. One bounded on the southwest by the hills of Elies Flat, on the northwest by the hills of the ledge flat extending north from Chub Cut, on the north by the line of flats running east in the direction of Three Hill Shoals till they strike the eastern face of the sound formed by the Brackish Pond Flats, the eastern boundary reaching towards Spanish Point and separated from the shoals north of it by the Ship Channel valley. The second sound is enclosed by the Brackish Pond Flats on the west, by the Bailey Bay Flats on the north and east, and by the main island on the south. The third is the Murray Anchorage sound, limited on the west by the Bailey Bay Flats, on the north and east by the Three Hill Shoals and the flats west of Mills Breaker. The third sound opened by a narrow deep valley (the Ship Channel) towards the sea, and communicated by a wide passage with the fourth sound, bounded by the ledge flats of the northwestern part of the Bermudas, — flats which extend unbroken from the north of Western Blue Cut to the Eastern Ledge Flats, — and on the southern edge by the line of the Three Hill Shoals and by the western extension of the Bailey Bay Flats. This fourth sound is in reality a double sound, as the western part is separated from the eastern by a narrow line of æolian heads, indicating probably the position of a cross line of dunes connecting the Ledge Flats and Bailey Bay Flats. Its northern edge was deeply indented, as is indicated by the many tongues of deep water cutting into the width of the ledge flats (Plate II.). Two smaller and indistinctly connected sounds are similarly indicated to the west of East Ledge Flats and to the west of Mills Breaker. On the eastern ledge flats there are also a number of deep pockets, already referred to, as well as many deep bights running into the ledge flats, indicating the position of valleys running more or less at right angles to the trend of the ledge flats.

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[1] Thomson, The Atlantic, I. 318.

The Southwest Breaker and Chaddock, Little, and Long Bars are the base of lines of æolian hills, once running parallel with the edge of the western and southern Ledge Flats hills.

This proto-Bermudian land must have resembled the Bermudian landscape of to-day, and has been reduced to its present condition by the same causes which we see at work to-day on the islands of the group, and which have acted more vigorously either on the faces most exposed to the prevailing winds, or upon æolian hills of a lower altitude than those of the main island.[1] The proto-Bermudian sounds vary in depth from six to twelve or thirteen fathoms, the deepest being the sound to the north of Three Hill Shoal.

I also agree with Rice and Heilprin that the amount of subsidence must have been "sufficient to account for the depth of water which marks the lagoon and inner sounds," and that "before this subsidence took place probably the entire area now covered by the Bermudian archipelago, and much more, were dry land." But I do not think that "it was at this time, doubtless, that the great sand dunes were elevated." On the contrary, I do not imagine the dunes to have been elevated, but to have perhaps been blown to their greatest height in the manner suggested from a broad coral sand beach.

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[1] "The prevalence of powerful winds on the south side would tend to elevate this side of the island, while the opposite side, not feeling this influence in any marked degree, would remain comparatively low and flat. In a period of subsidence the low side would naturally be the first to succumb to the waters, and would undergo submergence long before the elevated slopes. And this is precisely what appears to have taken place in the Bermudas." — Heilprin, Bermudas, p. 42.

Heilprin adopts the suggestion thrown out by Rice, that these æolian accumulations could only have been formed at a time when large areas of reef, and not a simple atoll ring, were exposed above the water level,[1] while it is perfectly true, as Heilprin says, that all the sand formed at the present day is derived from the destruction of the existing land masses, and not as a product of the disintegration derived from the growing reef, — a statement which by the way hardly agrees with the graphic description of the destruction of the coral reef off the south shore given by him a page or two before.

It does not seem to me necessary that there should have existed very wide areas of coral reefs for the formation of the Bermudian æolian hills. A reef of a width of 1,200 to 1,800 feet, such as are known to exist, seems to me ample to supply the material necessary for the formation of the æolian hills, especially if, as may have been the case judging by the soundings off the reef, there also existed a comparatively wide shallow bank outside of it. Taking the subsidence of the Bermudas as twelve fathoms, this belt could have been a belt of twelve to twenty fathoms, a shallow bank, the wear and wash from which would alone supply a large part of the material needed for the formation of the Bermudian dunes, and carry the topography now prevailing pretty well over the whole of the bank inside the ten or twelve fathom line. In addition, we should of course also have the supply derived from the reef itself. The amount of material which can be supplied from a comparatively small reef and its adjacent bank I saw well illustrated at the Sandwich Islands. A number of dunes were constantly travelling inland from the beach at Spreckelsville, and had covered to a considerable elevation a great part of the isthmus connecting the two islands which constitute Maui. Very high dunes, from 120 to 180 feet, of nearly a mile in width, occur on the shores of the Baltic, the material of which is derived from a comparatively narrow beach range.

I fully agree with those who before me have examined the Bermudas, and who consider that subsidence has brought about the existing condition of the islands and sounds. But that is a very different thing from assigning to the corals now growing the formation of the islands owing to this subsidence. That the proto-Bermudian land was of elliptical shape, and owed its existence to the action of winds sweeping over an extensive coral beach, from which was gathered the material which now form the solidified æolian hills of the Bermudas, no one can question. But there is no evidence to show that the original annular coral reef was formed during subsidence. That reef has disappeared, and nothing is left of it except the remnants of the æolian ledges, extending to sixteen or seventeen fathoms outside of the reef ledge flats, ledges which owed their existence to the material derived from it, — the former æolian hills of the proto-Bermudian land. Remnants of such ledges and former æolian hills are the rocks forming the outer ledge flats, the breakers all along the south shore, the Mills Breaker, the North Rocks, the Chub Heads, the Southwest Breaker, and others.

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[1] The Bermuda Islands, p. 46.

The evidence of the extent of the subsidence which has taken place at the Bermudas is very clear. It is based upon the depth of the sounds and of some parts of the lagoon, the existence of æolian rock at a depth of fifty feet below low-water mark, and the excavation of red earth from a depth of forty-eight feet below low-water mark on Ireland Island,[1] and at eighteen feet below low-water mark in the entrance to St. George Harbor. Numerous caves and caverns occur in the Bermudas, which have been fully described by previous writers. Many of them, although extending far below low-water mark, could only have been formed when the islands were at a greater elevation than at the present day. In the caves, as well as smaller ponds or embryo sounds close to the shores, the porosity of the æolian rock, as well as its cavernous and honeycombed structure, is indicated by their connection with the sea. The water rises and falls in the caverns with the tides, and the beat of the diminutive waves against the subterraneous shores of the caves closely follows that of the sea outside.

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[1] Sir Wyville Thomson has given a section of the rocks exposed during the excavation for the basin of the dry dock at Ireland Island (Atlantic, I. 319.) Huge stalactites and stalactites covered with Serpulæ extending below low-water mark in some of the caverns clearly indicate the effects of the subsidence. Trunks of the Bermuda cedar have been found in the red earth at a depth of forty-eight feet in the excavation of the dry dock, and have also been dredged from the bottom of Hamillon Harbor in a depth of five fathoms. This is of no great value as evidence, since the stumps may have fallen in from the surrounding hillsides, have floated off, and become water-logged. According to General Lefroy, one of the great bogs of the main island extends to a depth of forty or fifty feet below the sea level, and indicates the depth to which one of the sinks of the proto-Bermudian land reached before the subsidence took place which resulted in the present configuration of the islands.

At the Bermudas we find nothing corresponding to the ocean holes of the Bahamas, unless it be that such cavernous sinks and indentations as occur all along the shores, and which can be detected on the edges of the reefs and ledges, or in the circular areas where the depth is sometimes greater by two to three fathoms than over the adjoining area, may correspond to ocean holes, but only on a smaller scale of depth.

Heilprin thinks "that the height of land in the archipelago was formed during a period of elevation." It seems to me more natural to suppose that the Bermudas were formed during a period of rest, when the level of the reef was stationary, and they were flanked by a broad sand beach with flats perhaps bare at low water. These would supply an abundant material for the formation of such dunes as we now find, and may imagine to have existed on the northern edge of the Bermudas and on the flats which determine the shape of the proto-Bermudian lagoons.

While I fully agree to the all-important part which subsidence has played in shaping the Bermudas as they now exist, I cannot trace any connection between these facts and the proposition that "the existence of an atoll in the present position of the Bermudas is not demonstrable." We certainly have a group of æolian hills formed from an annular ring of coral reefs which flourished when the land was at least seventy feet higher than at present. But the facts we observe on the islands to-day do not shed one ray of light on the question of the Darwinian theory of the formation of atolls. The position of the reef to which the Bermudas owe their origin can only be surmised, — and probably very correctly, — but we cannot state that it was formed during a period of subsidence, and have no data regarding this point. Subsidence has given to these islands their present configuration. But it is begging the question to state that the formation of the proto-Bermudian coral reef, about which Heilprin himself is careful to say we know nothing, if it does "not prove the correctness of the Darwinian theory of the formation of coral islands, measurably sustains it." [1]

We may also agree with him in the conclusion that the present form of the Bermuda Islands bears no relation to the ring of an atoll,[2] that the existence of an atoll in the present position of the Bermudas is not demonstrable, and that the lagoons and sounds were formed, as Rice first showed, during a period of subsidence.[1] But granting all this, what is the connection of an island group which according to him has no relation to the ring of an atoll, of an island for which the existence of an atoll cannot be demonstrated, with the Darwinian theory of the formation of coral reefs? How can the conclusions arrived at by Heilprin be reconciled with the following statements made by him: —

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[1] "The question as to what form of coral structure the Bermudas actually are — what constitutes their fundament, and how they were built to their existing level — still remains unanswered, and possibly we may never be able to answer." — Bermudas, p. 47.

[2] Heilprin says: "In the case of the Bermuda Islands, which limit the field of my own investigations in this direction, I am confident that, whatever may have been the original construction of the region, the present lagoon features have been brought about through subsidence; and this conclusion was reached before me by

"It will be seen that these results, so far as they go, are in absolute harmony with the views which Mr. Darwin entertained regarding the structure of these islands. They do not prove the correctness of the Darwinian hypothesis of the formation of coral islands, but they measurably sustain it; on the contrary, they are largely opposed to the requirements of the substitute theory which has been recently proposed. Elevation and subsidence are both shown to have marked the region in its development, and these conditions are more in consonance with the Darwinian hypothesis than with any other."[2]

Investigators have been carried away by the simplicity of the theory of subsidence propounded by Darwin, and it is only of late years since a mass of observations have been made which could not be explained by the prevailing theory that we have at last realized how complicated the problem is. Heilprin, as well as others before him, has truly said, "We may not yet have fathomed the true method of the formation of coral islands." But I must differ from him *in toto* when he says, "but such evidence as I was able to obtain at the Bermudas failed to convince me of the erroneousness of the time-honored theory of subsidence."[3]

The exploration of the Bahamas and of the Bermudas has brought into prominence a condition of things relating to the formation of coral reefs, the bearing of which had not been realized before. It is perhaps one of the most significant examples of how little we as yet know of the history of the formation of the coral reefs.

Professor Rice, who seems to have been amply satisfied with the subsidence theory." — Bermudas, p. 75.

[1] Heilprin has well stated the conditions of the disintegration of the land when he says: "The difficulty in the problem entirely disappears if we admit subsidence, and, as has already been seen, the positive evidences of subsidence are ample. On no other theory, it appears to me, can the waste of the cliffs on the south shore be explained. The direct evidences of subsidence, moreover, do not come from a single point in the archipelago; they are found from Ireland Island and Hamilton Sound, through the main island, to St. George."

[2] Bermudas, p. 46.

[3] Bermudas, p. 21.

# EXPLANATION OF THE PLATES.

## PLATE I.

Bermuda Islands. Reduced from U. S. Hydrographic Chart, No. 27.

## PLATE II.

Fig. 1. The Challenger and Argus Banks to the southwest of Bermuda.
Fig. 2. Section from Somerset Island across the Challenger and Argus Banks. Depth in fathoms, horizontal scale, 1 inch = 10 miles.
Fig. 3. Section north-northeast from North Rock into 1,370 fathoms.
Fig. 4. Section southeast from Castle Harbor into 1,240 fathoms.

## PLATE III.

The Bermuda Islands from Gibbs Hill.

## PLATE IV.

Mullet Bay, St. George Island. Characteristic Æolian Hills in the background.

## PLATE V.

Bare Hills on the North Shore of the Western Entrance to St. George Harbor.

## PLATE VI.

Shore of Harrington Sound.

## PLATE VII.

Webb's Pond.

## PLATE VIII.

North Rock.

## PLATE IX.

Deep Cut through Æolian Rock, Warwick.

### PLATE X.

Sink, Warwick, South Shore.

### PLATE XI.

Sand Dunes, Elbow Beach.

### PLATE XII.

Sand Dunes back of Elbow Beach.

### PLATE XIII.

Devil's Hole. Characteristic hardened Æolian Rock.

### PLATE XIV.

Lagoon near Tuckerstown.

### PLATE XV.

Entrance to Hungry Bay.

### PLATE XVI.

Æolian Cliffs near Admiralty House, North Shore.

### PLATE XVII.

Pulpit Rock off Ireland Island.

### PLATE XVIII.

Half-sunken Ledge, North Shore, off Boat Harbor.

### PLATE XIX.

Æolian Cliffs, South Shore, near Middleton Beach.

### PLATE XX.

Æolian Cliffs, South Shore, Elbow Bay.

### PLATE XXI.

Ledges and Islets off Castle Harbor.

### PLATE XXII.

Æolian Cliffs with Serpuline Atolls, South Shore.

## PLATE XXIII.

Æolian Rock Pinnacles and Serpuline Atolls, South Shore.

## PLATE XXIV.

Serpuline Atolls, South Shore.

## PLATE XXV.

Serpuline Atolls, South Shore.

## PLATE XXVI.

Fringing Serpuline Reefs, South Shore.

## PLATE XXVII.

Pitted and Honey-combed Æolian Rocks, Harrington Sound.

## PLATE XXVIII.

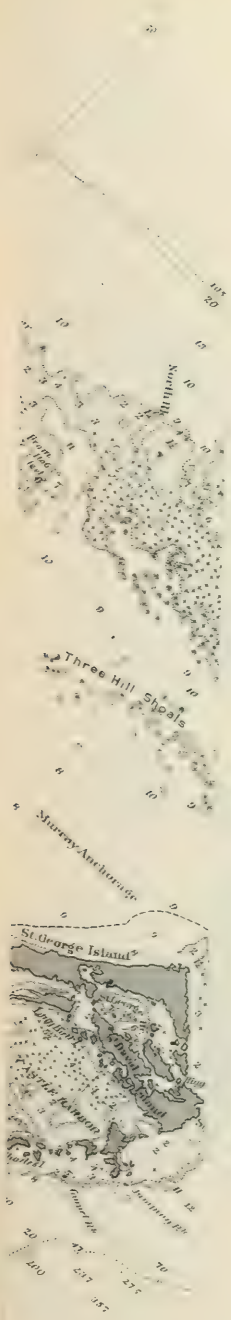
Ledge showing Passage of Æolian Rock to Base Rock, Boat Harbor, North Shore.

## PLATE XXIX.

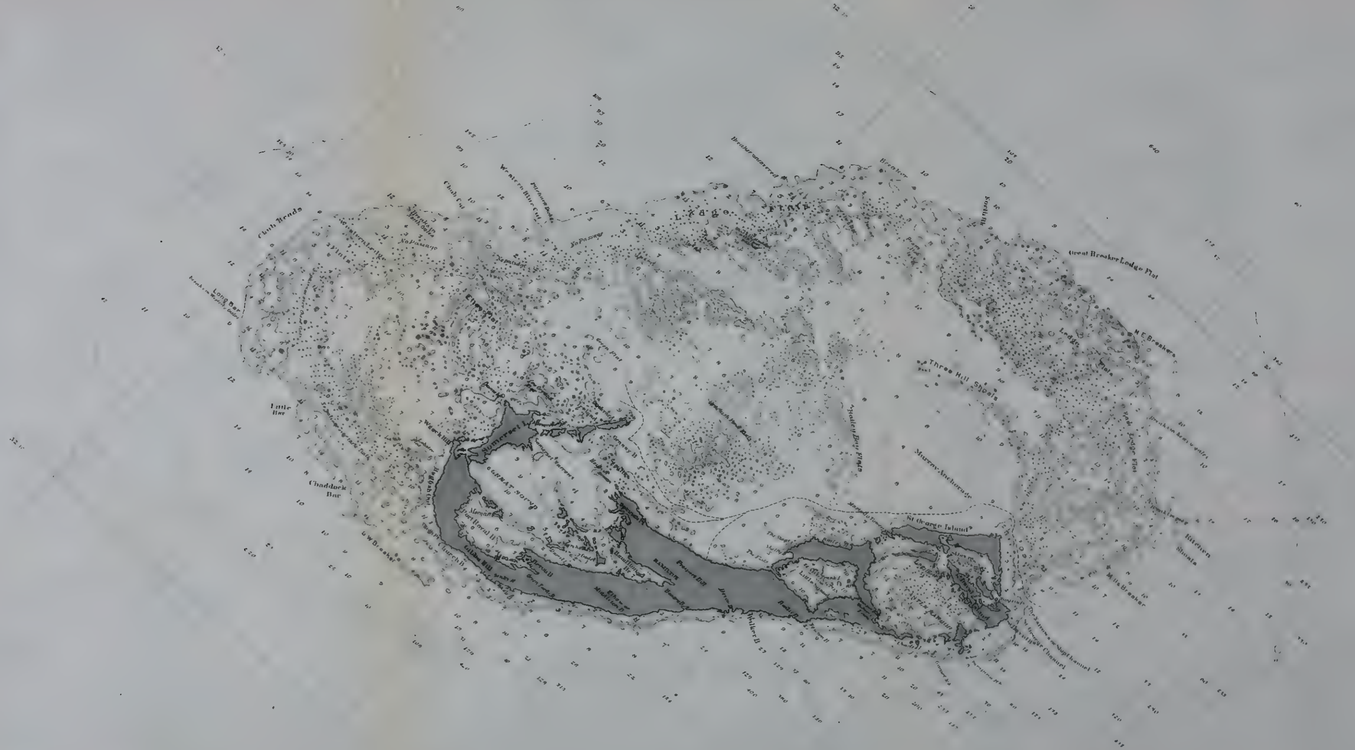
Pot-holes, Harrington Sound.

## PLATE XXX.

Pseudo-Palmetto Stumps, North Shore.


Three Hill Shoals
Murray Anchorage
St. George Island
David Island

# BERMUDA ISLANDS.


Chub Heads
Long Bar
Little Bar
Chaddock Bar
Chub Cut
Western Blue Cut
No Passage
Ledge Flat
Breaker
Great Breaker Ledge Flat
N.E. Breakers
Three Hill Shoals
Murray Anchorage
St George Island
Kitchen Shoals
Mills Breaker
Wreck Hill
Somerset I.
Great Sound
Green Flat
Port Royal B.
Church B.
Gibbs Hill
Hamilton
Prospect Hill
Walker B.
Little Sound
St David's
Castle Harbour
Harrington Sound
The Flatts
The Narrows

F. Meisel lith. Boston

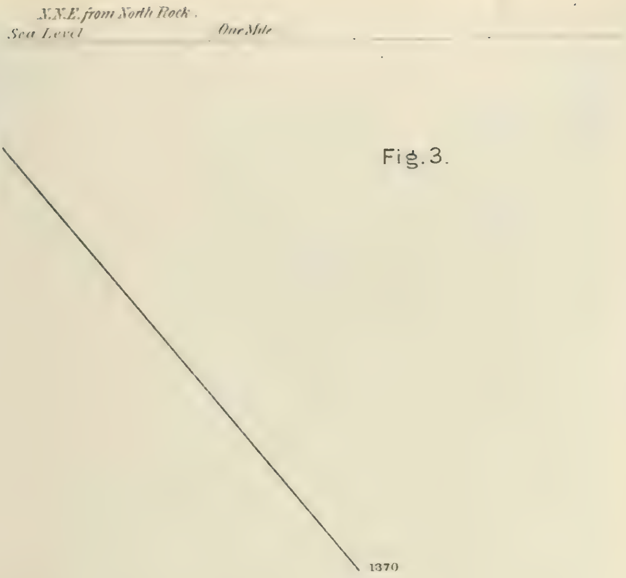

N.N.E. from North Rock.
Sea Level
One Mile
1370

Fig. 3.

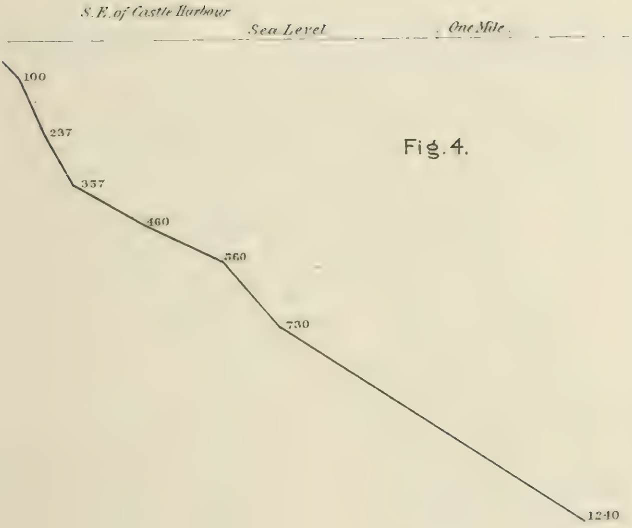
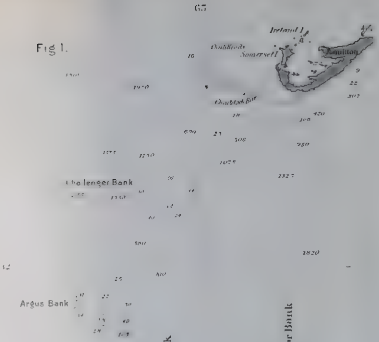

S.E. of Castle Harbour
Sea Level
One Mile
100
237
357
460
560
730
1240

Fig. 4.

B.Meisel lith Boston.

Fig 1.



65
Ireland I
Somerset I
Hamilton
Cha lenger Bank
Argus Bank
16
1970
9
18
670
21
506
100
420
950
307
22
1075
1250
1327
580
1820
810
25
40
30

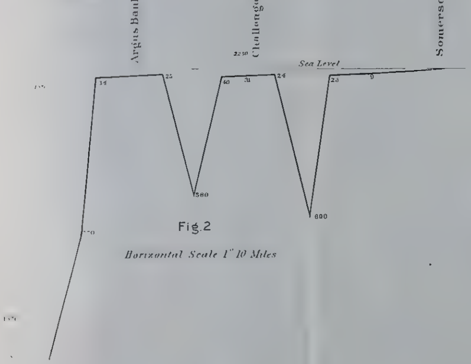


Fig. 2

Horizontal Scale 1" 10 Miles

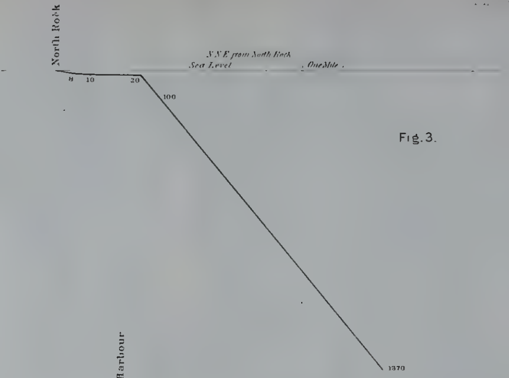


Fig. 3.

Depths in Fathoms.

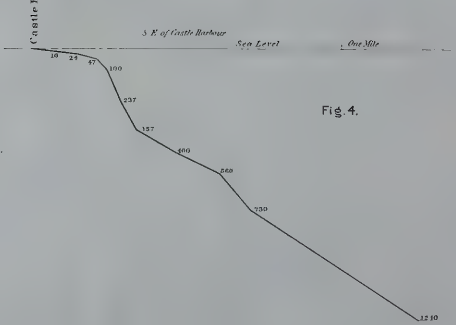
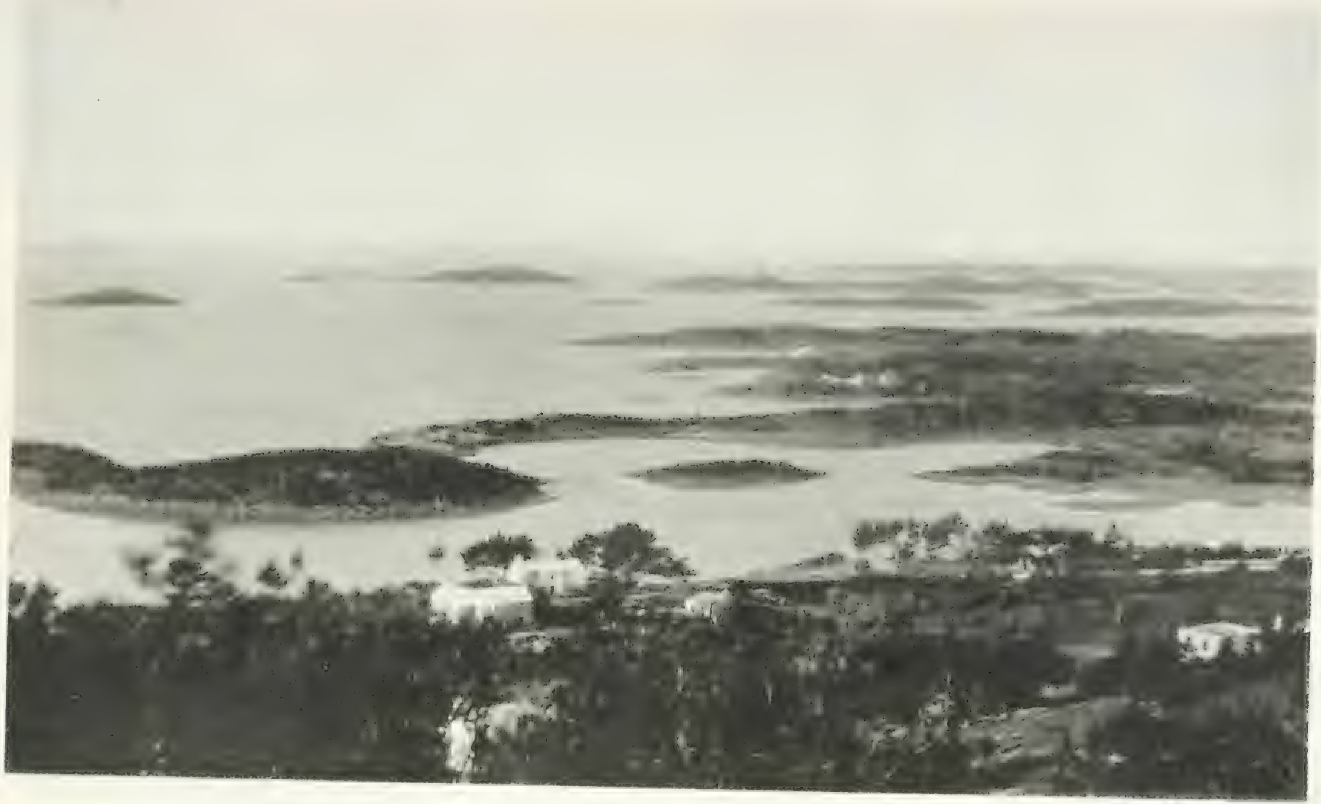


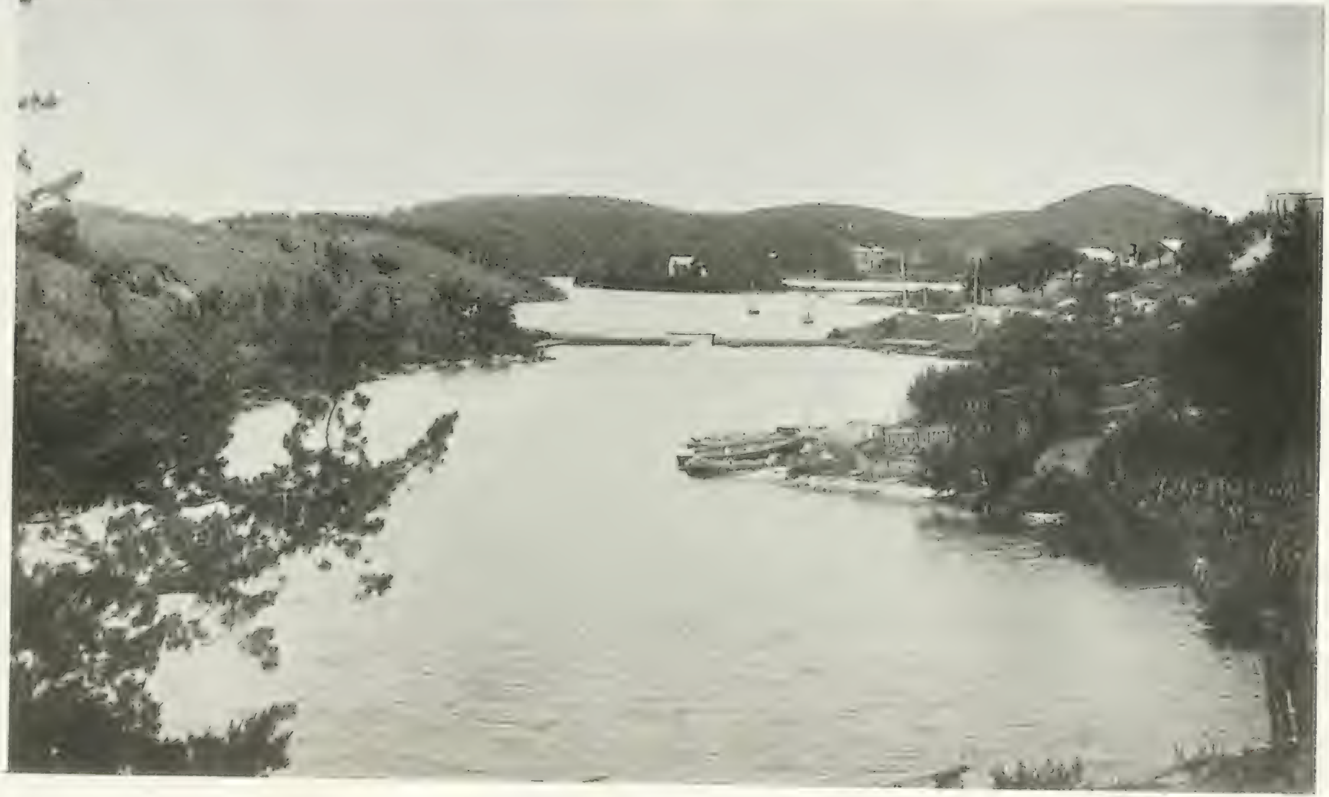
Fig. 4.

PLATE III.



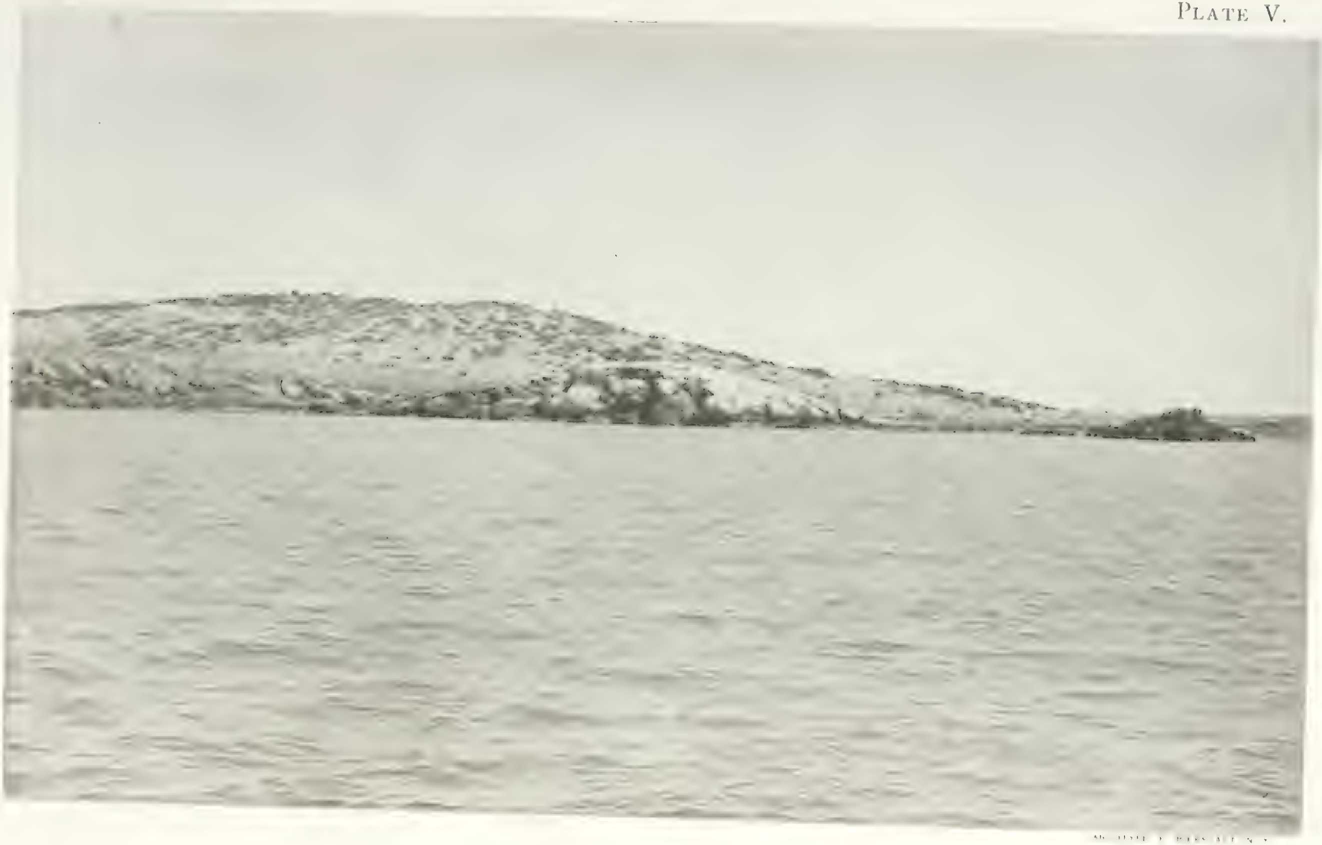
ARTOTYPE, E. BIERSTADT, N. Y.

THE BERMUDAS FROM GIBBS HILL.

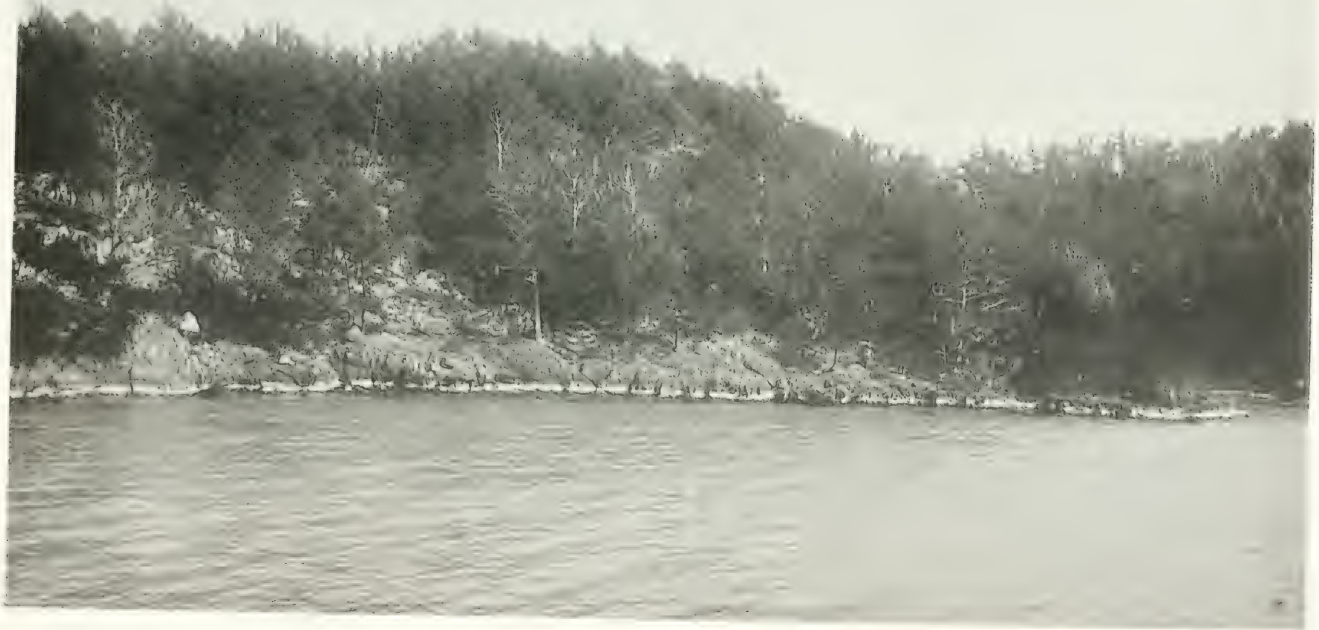


ARTOTYPE E. BIERSTADT, N. Y.

MULLET BAY.



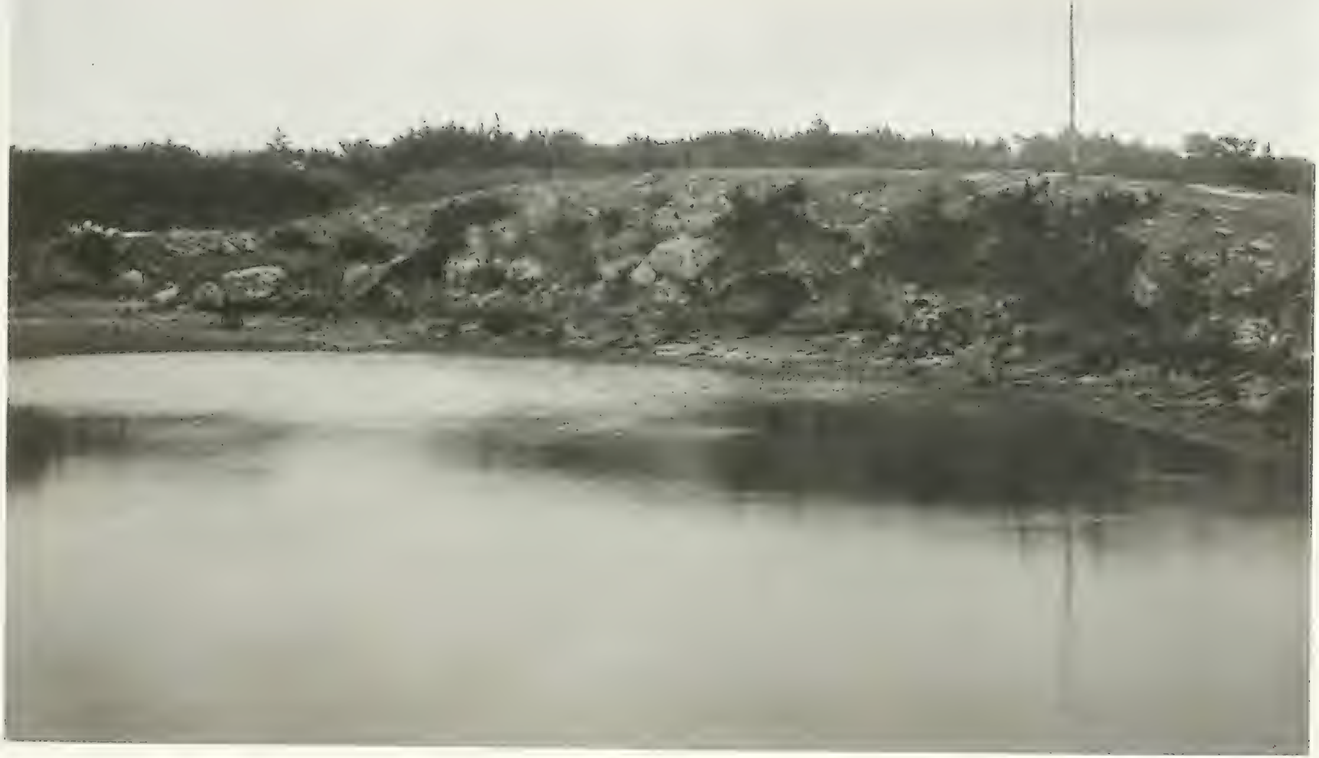
NORTH SHORE ENTRANCE TO ST. GEORGE.



[illegible]

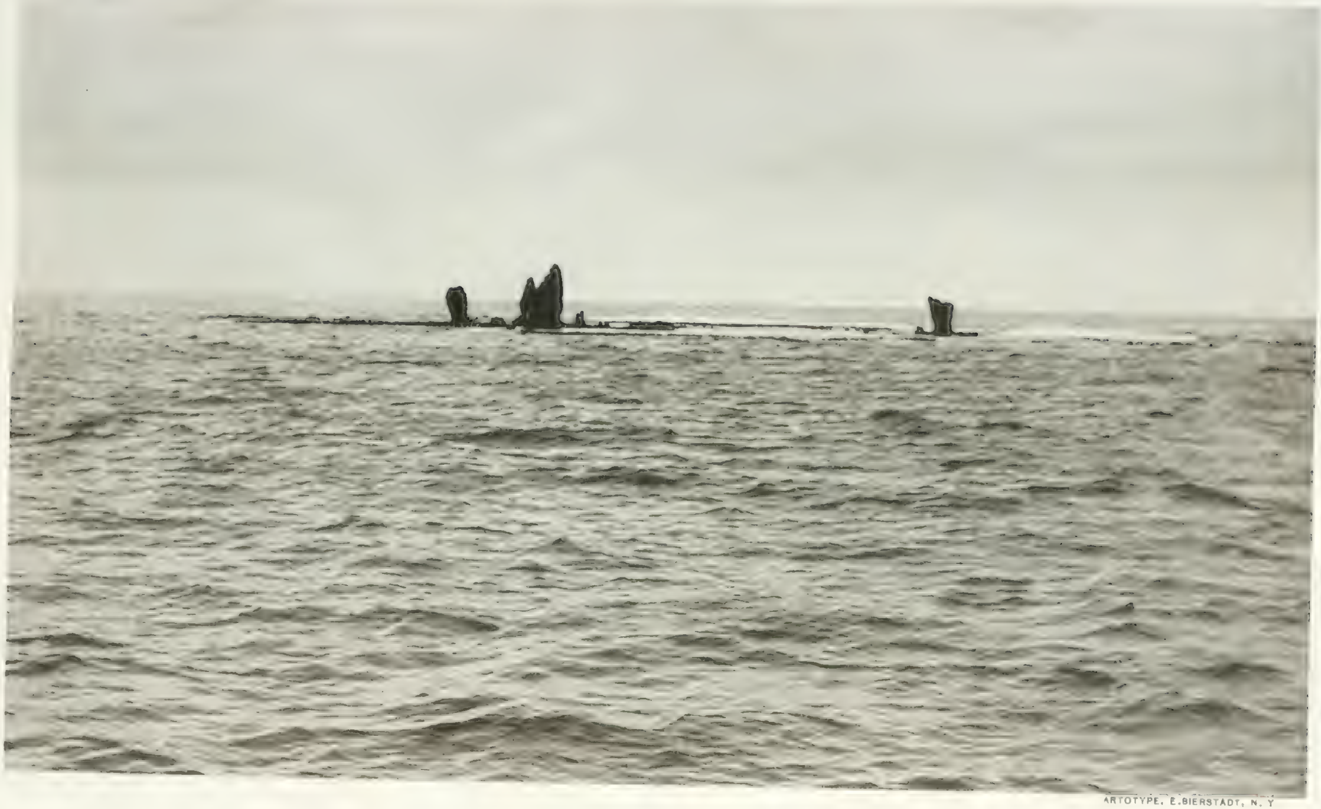
HARRINGTON SOUND SHORE.

Plate VII.



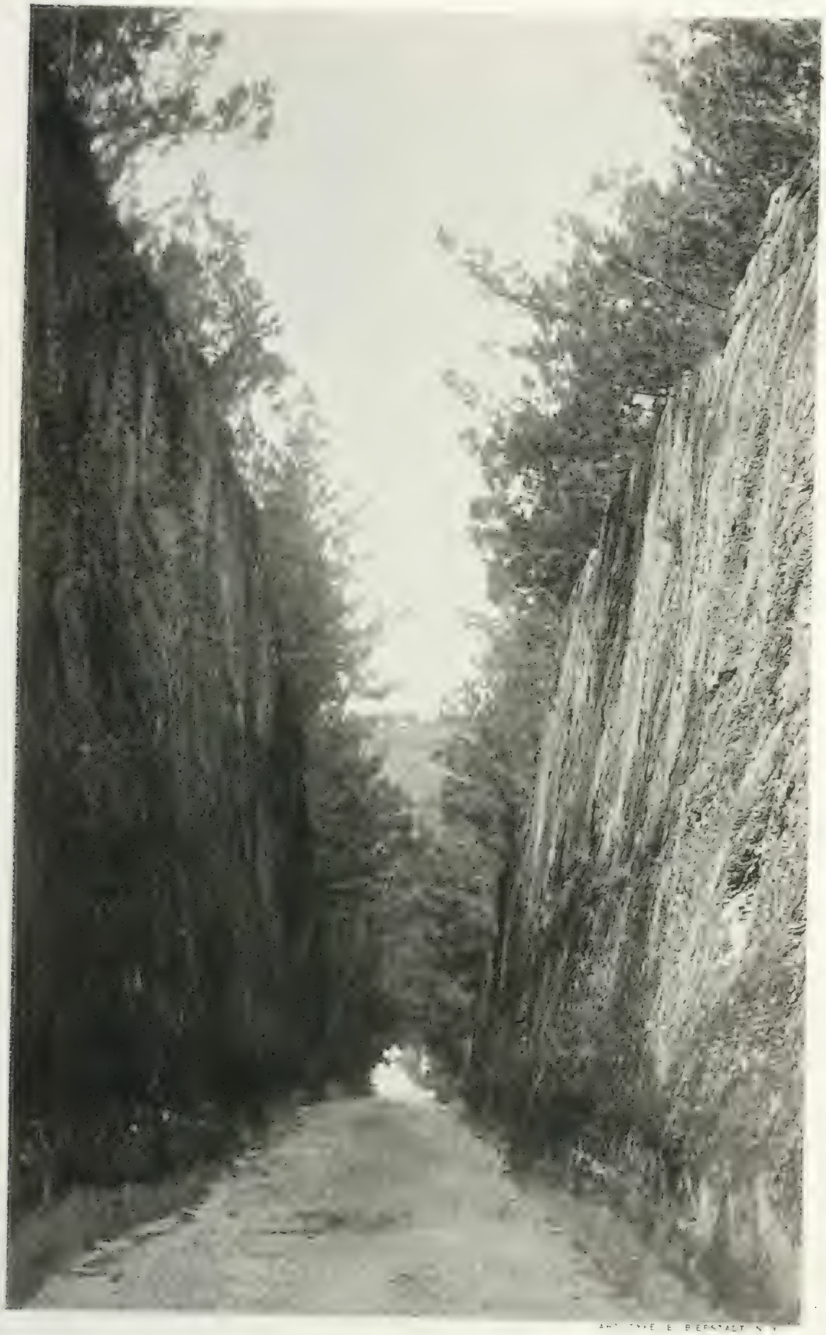
ARTOTYPE, E. BIERSTADT, N. Y.

WEBB'S POND.



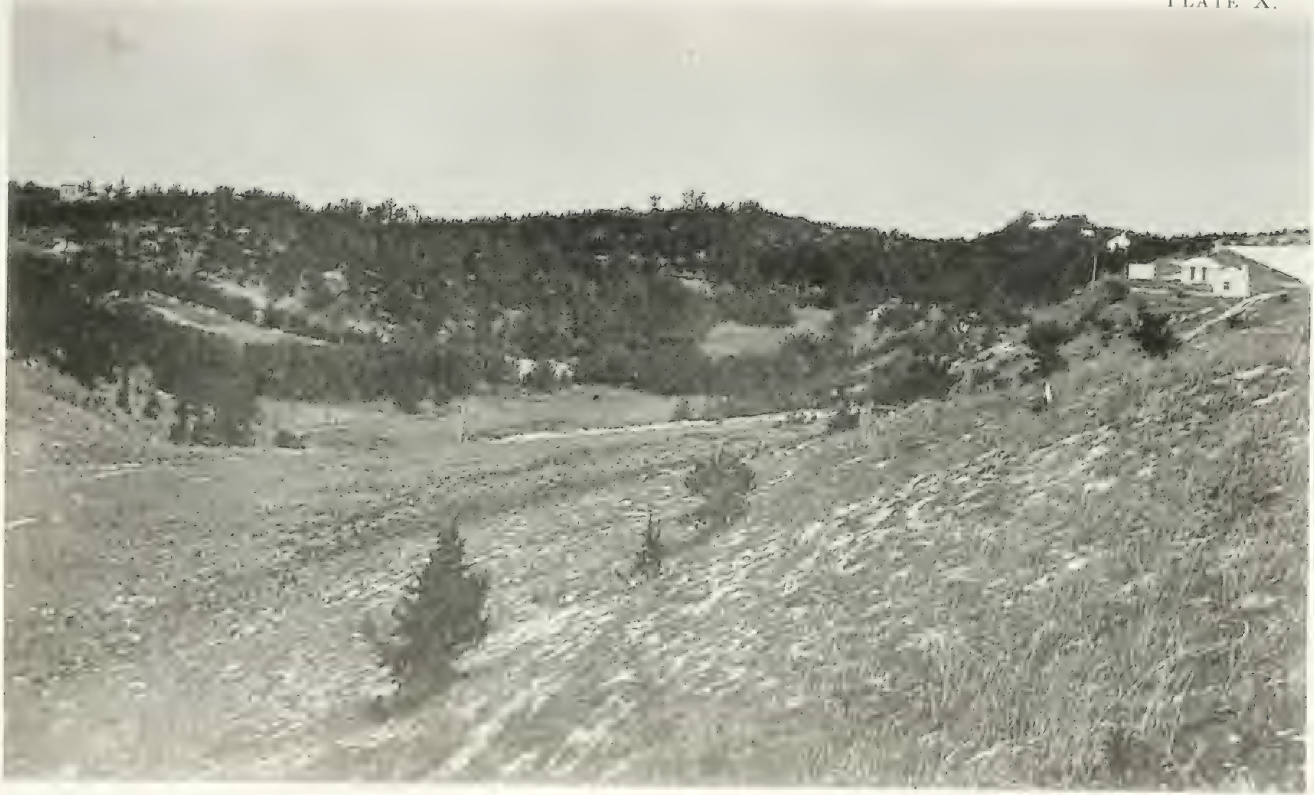
ARTOTYPE, E. BIERSTADT, N. Y.

NORTH ROCK.



ARTOTYPE E. BIERSTADT N.Y.

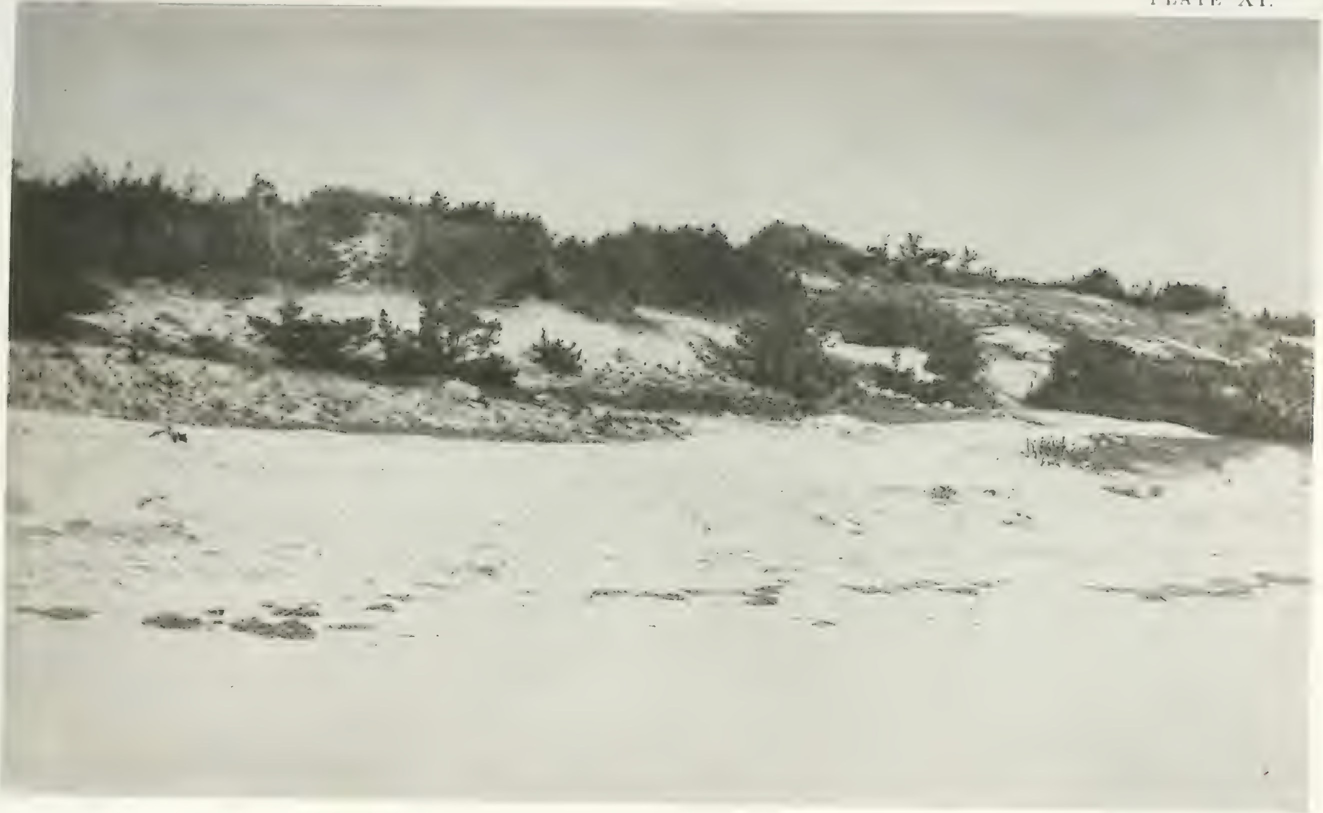
DEEP CUT, WARWICK.



ARTOTYPE. E. BIERSTADT. N. Y

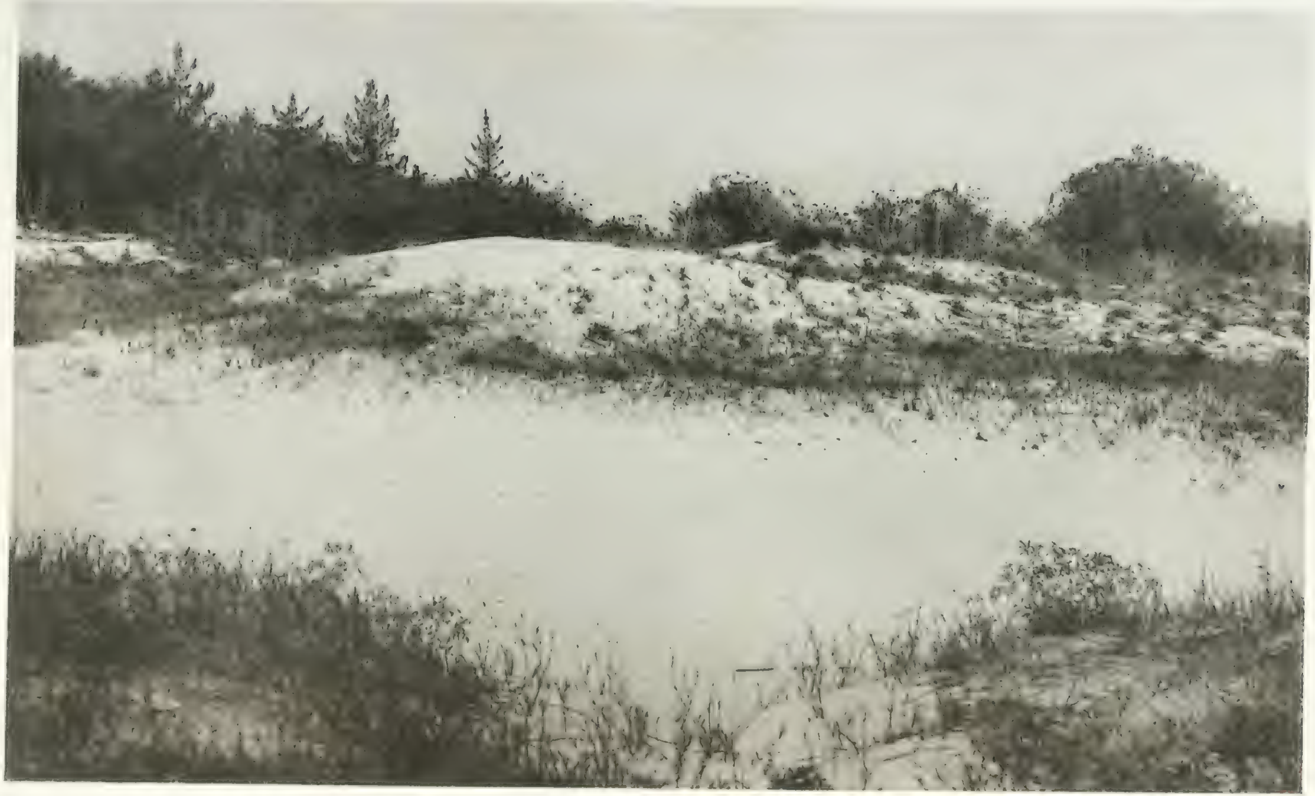
SINK. WARWICK.

PLATE XI.



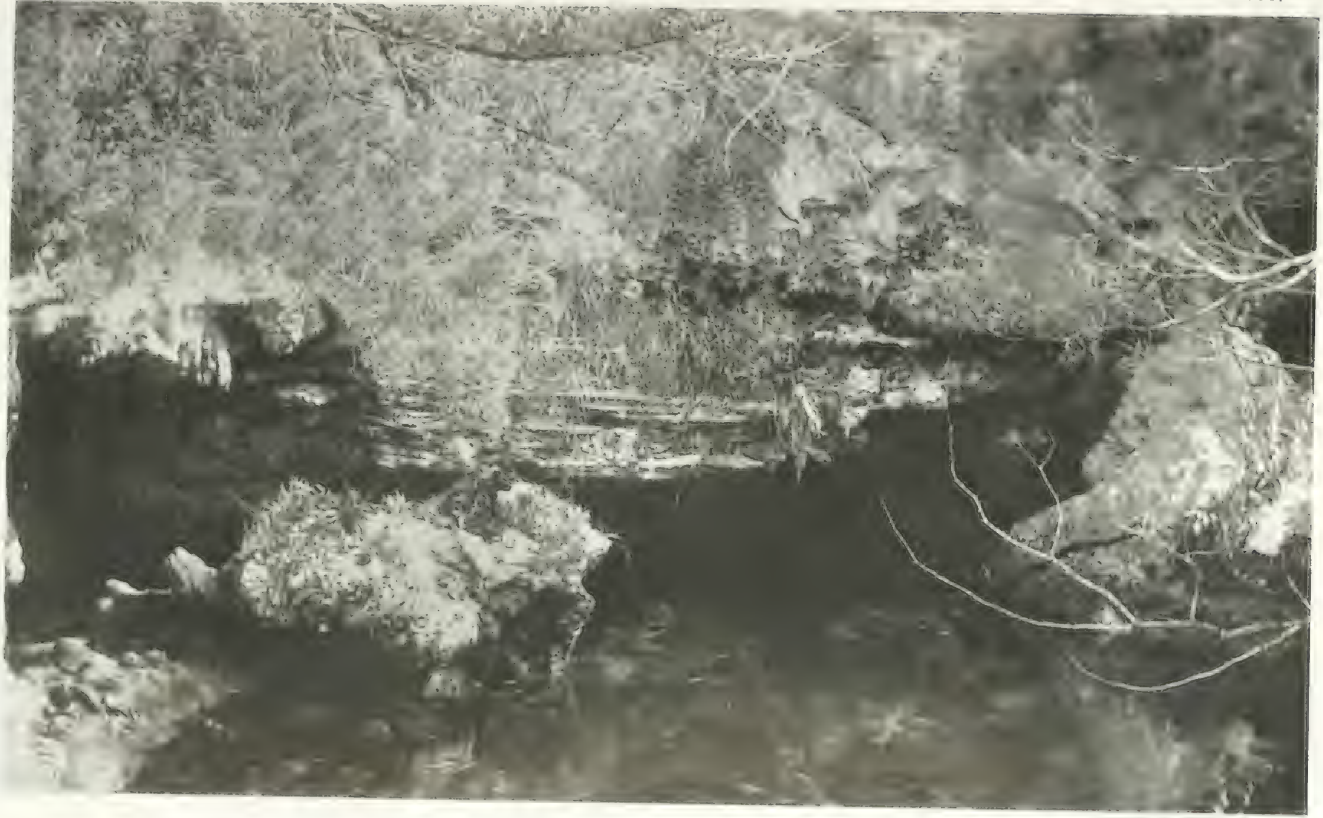
ARTOTYPE E. BIERSTADT, N. Y.

SAND DUNES, ELBOW BEACH.



[illegible]

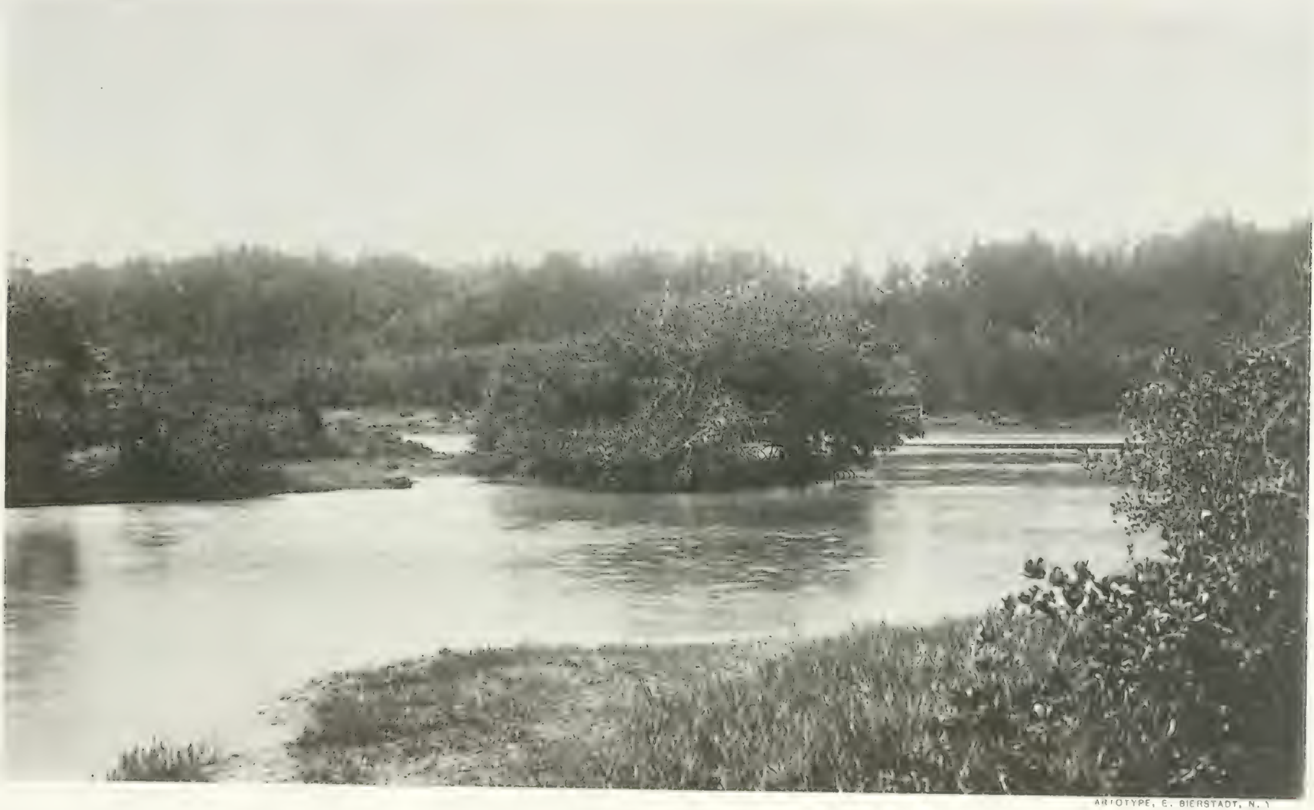
DUNES BACK OF ELBOW BEACH.



[illegible]

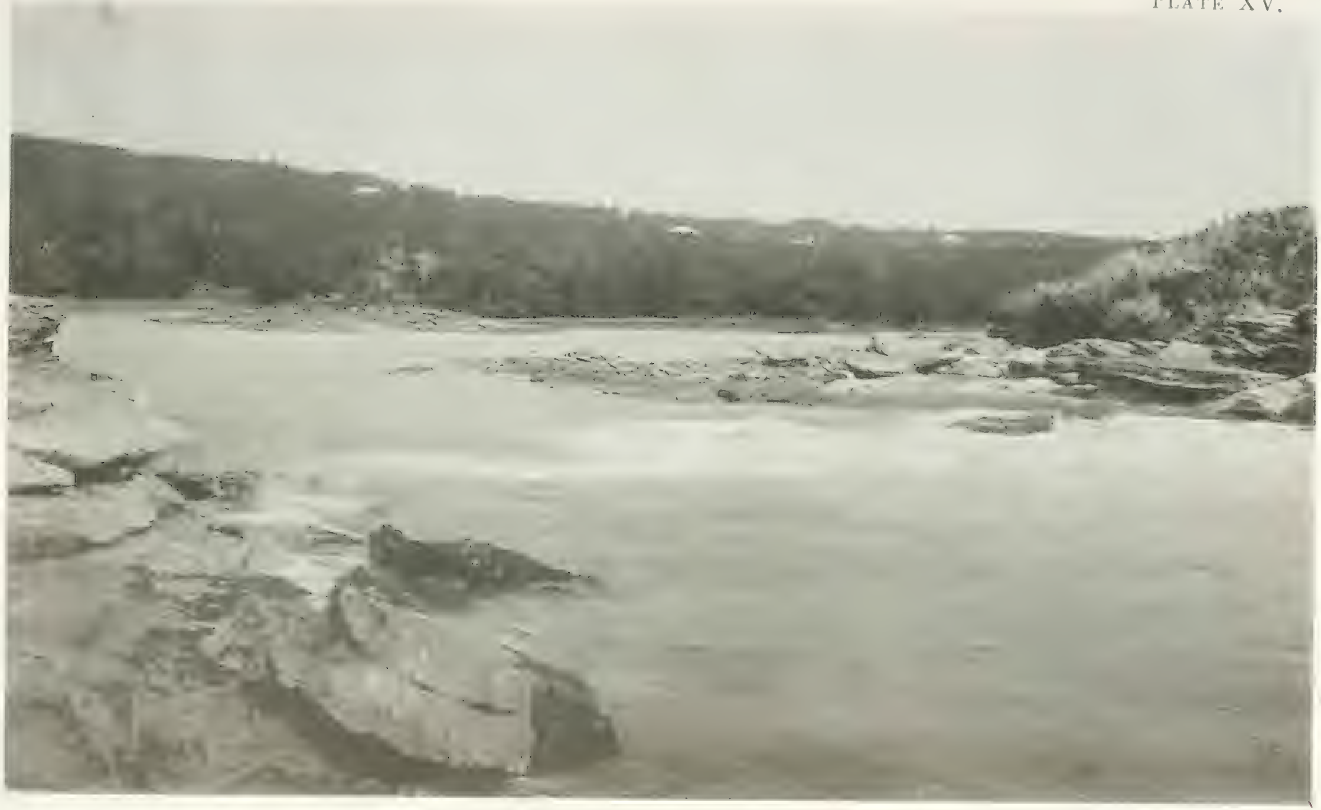
DEVIL'S HOLE.

PLATE XIV.



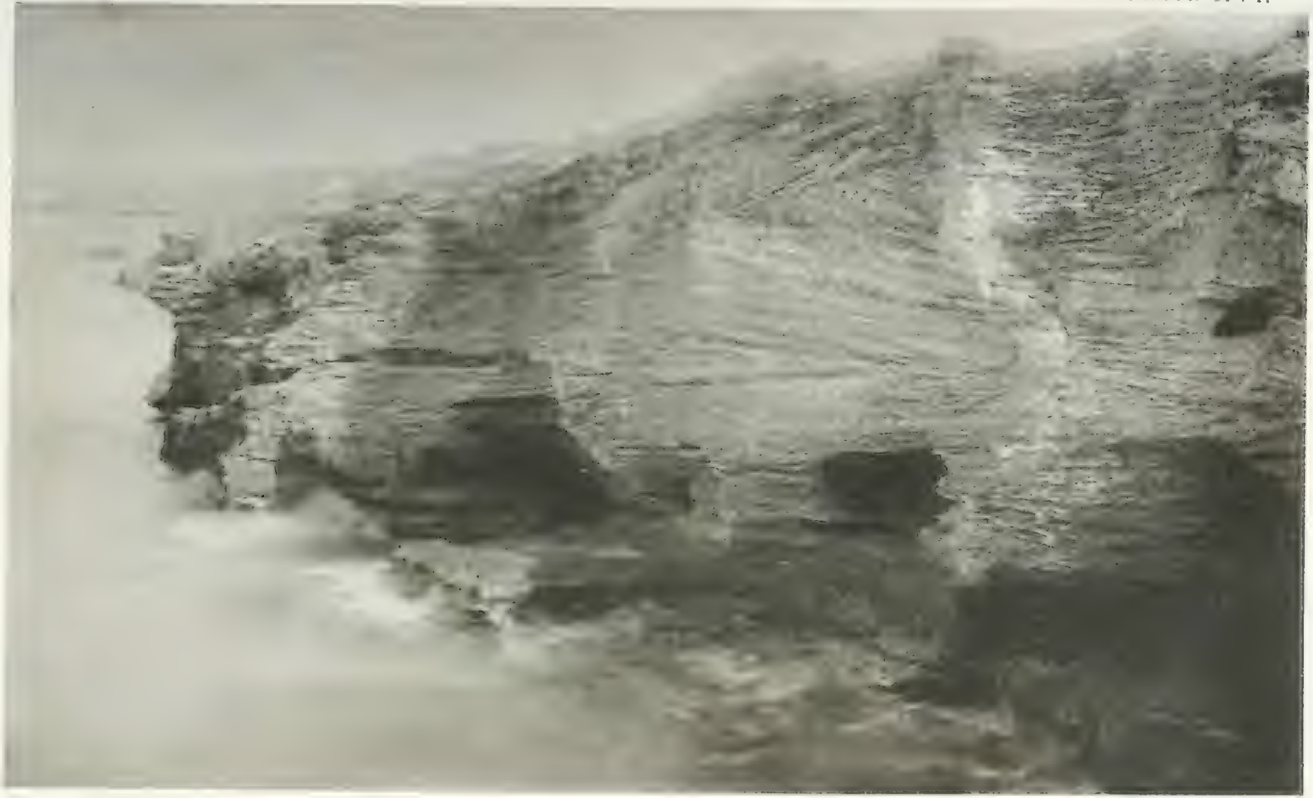
ARTOTYPE, E. BIERSTADT, N. Y.

LAGOON TUCKERSTOWN.



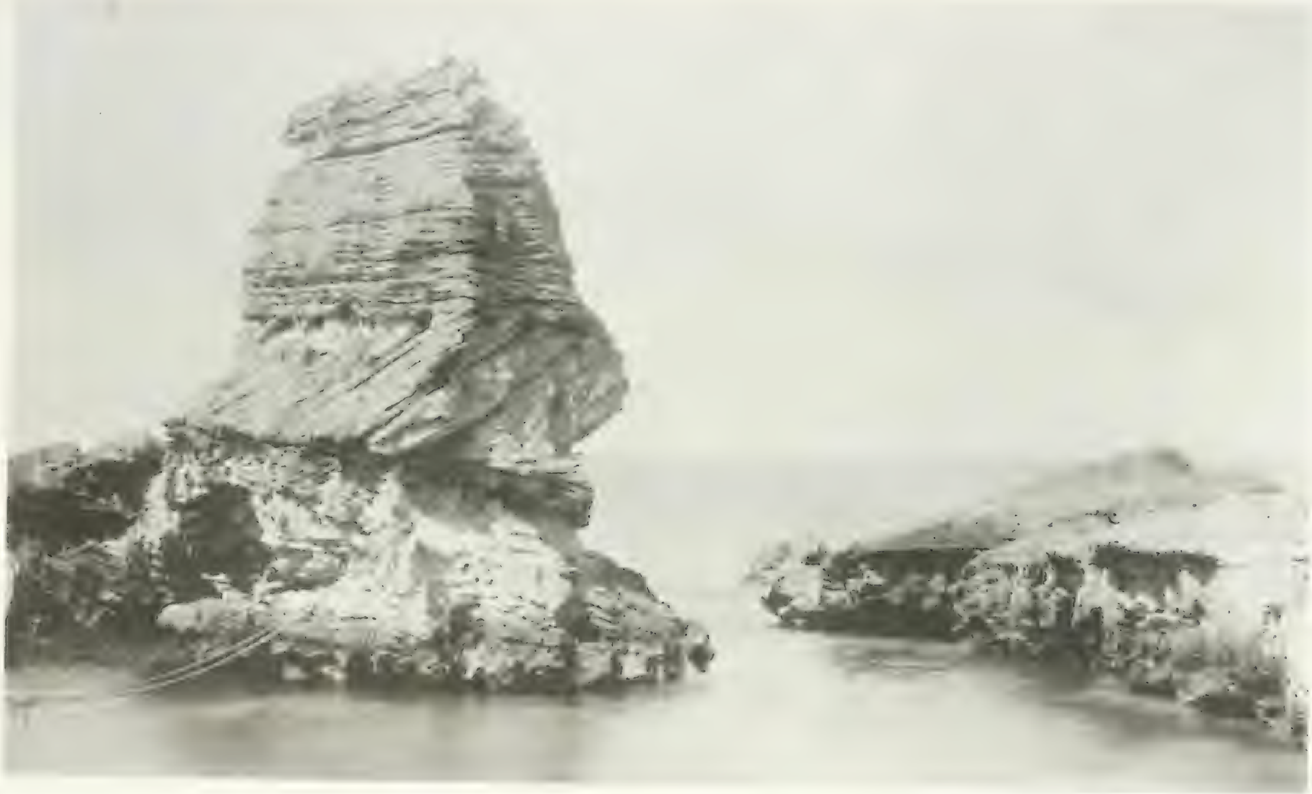
ARTOTYPE, E. BIERSTADT, N

ENTRANCE TO HUNGRY BAY.



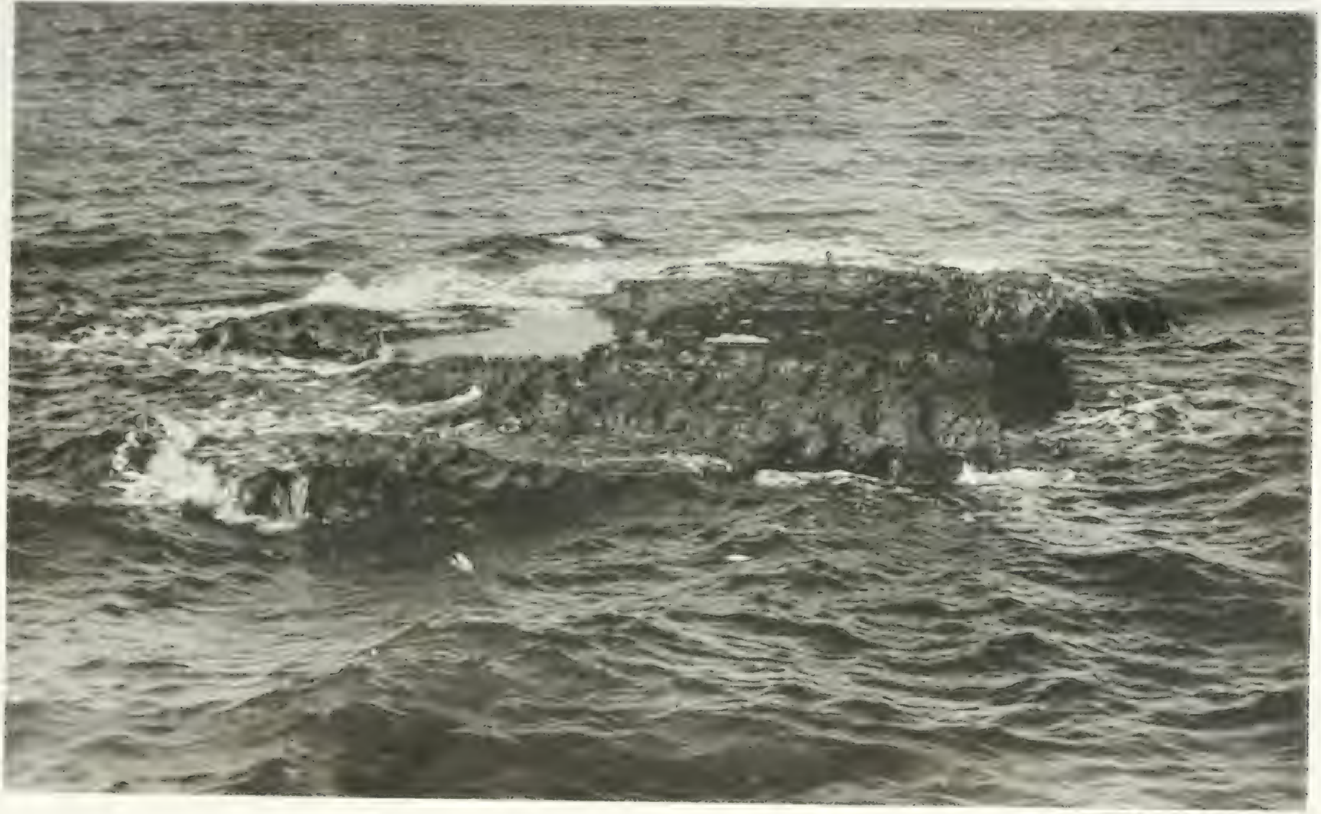
ARTOTYPE, E. BIERSTADT, N. Y.

ÆOLIAN CLIFFS, NORTH SHORE.



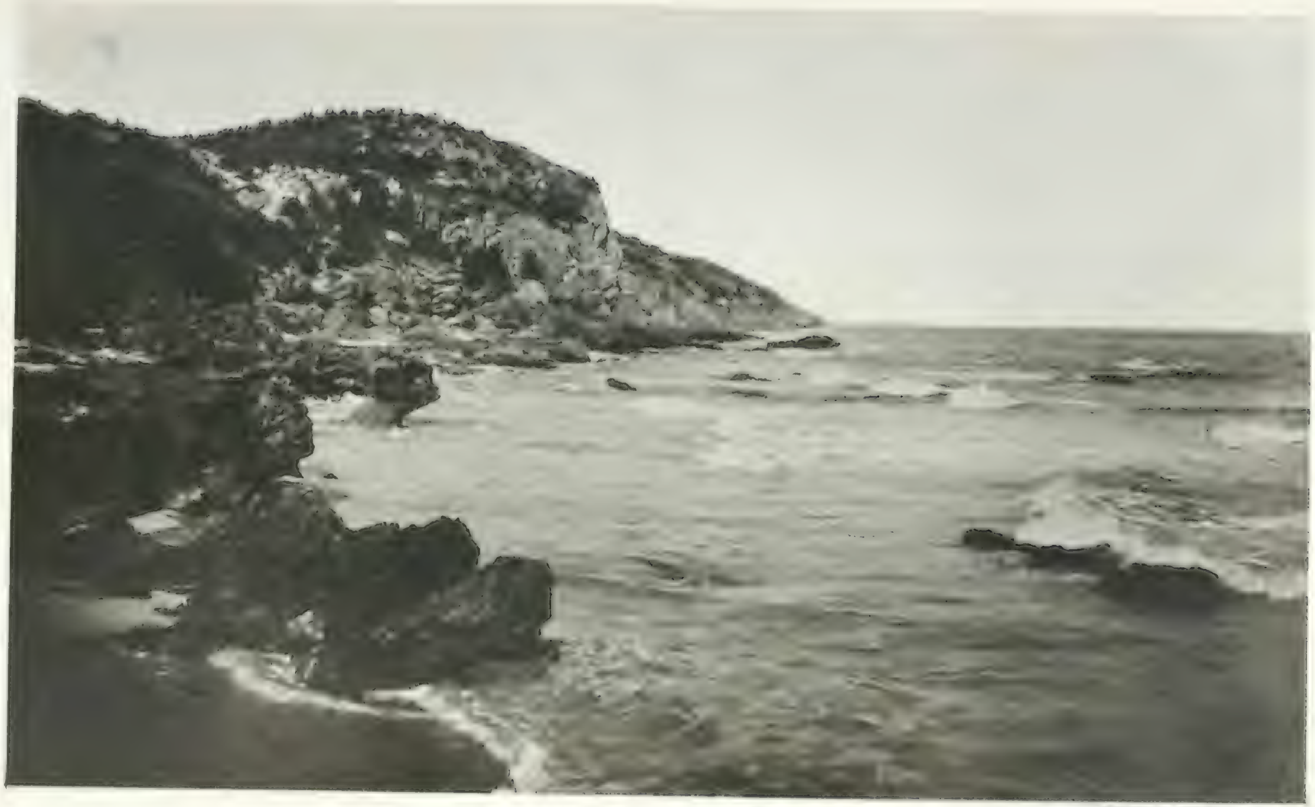
ARTOTYPE, E. BIERSTADT, N.Y.

PULPIT ROCK. IRELAND ISLAND.



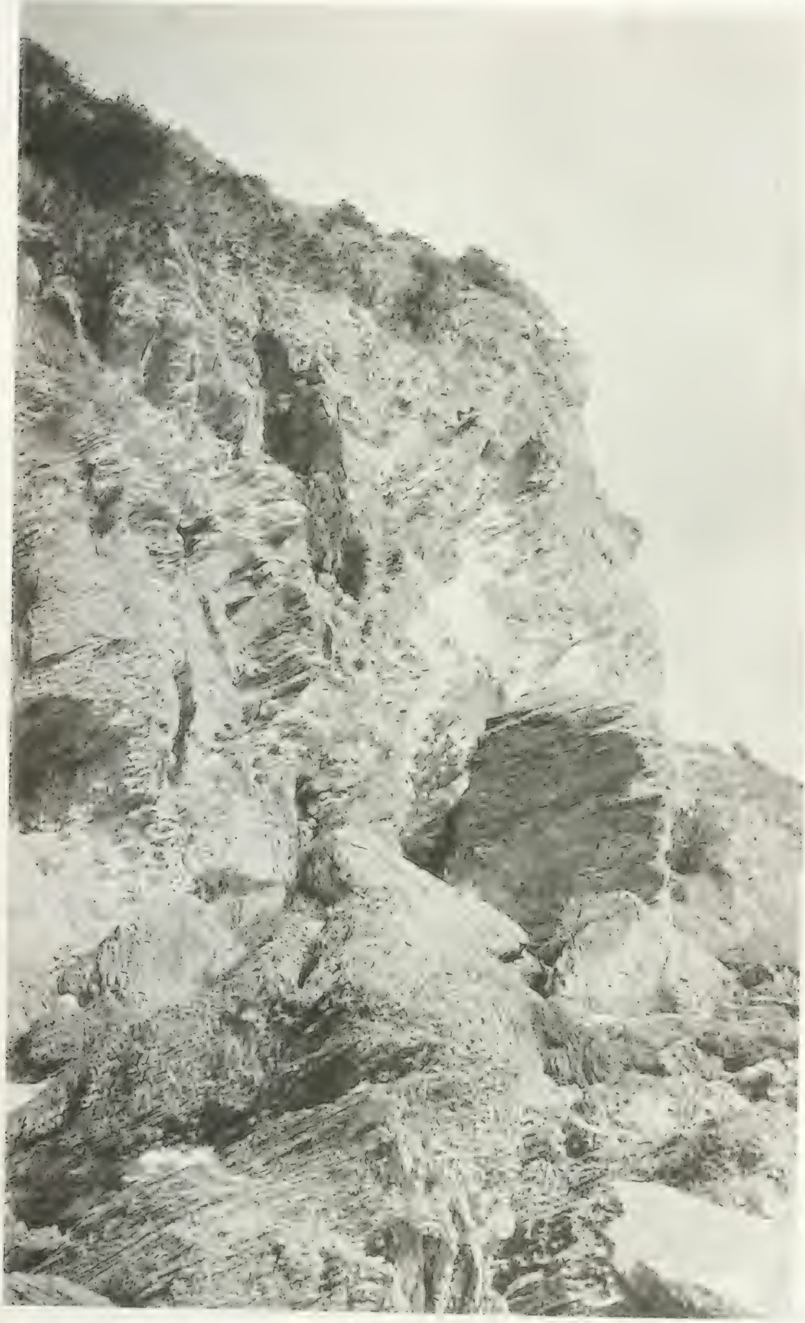
ÆOLIAN LEDGE, NORTH SHORE.

PLATE XIX.



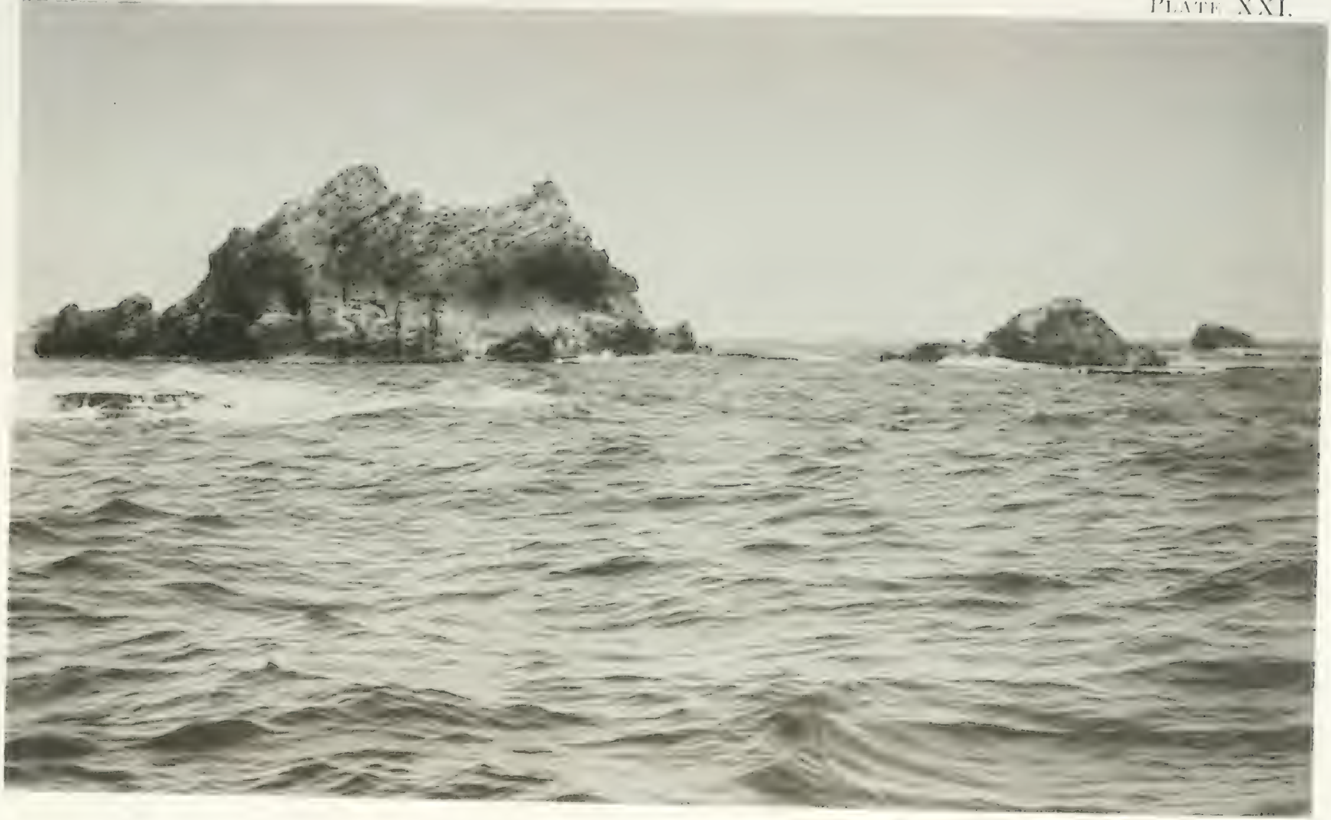
ÆOLIAN CLIFFS NEAR MIDDLETON BEACH.

PLATE XX.



ARTOTYPE E. BIERSTADT, N.Y.

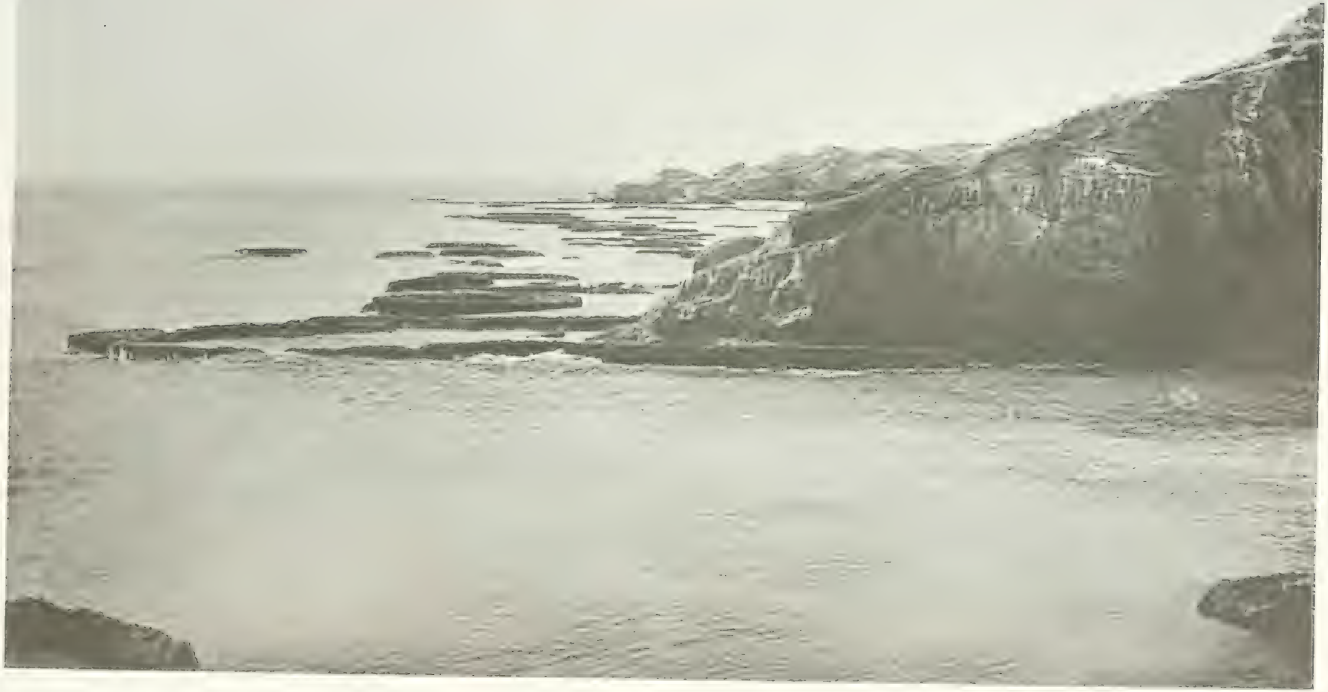
CLIFFS, SOUTH SHORE.



[illegible]

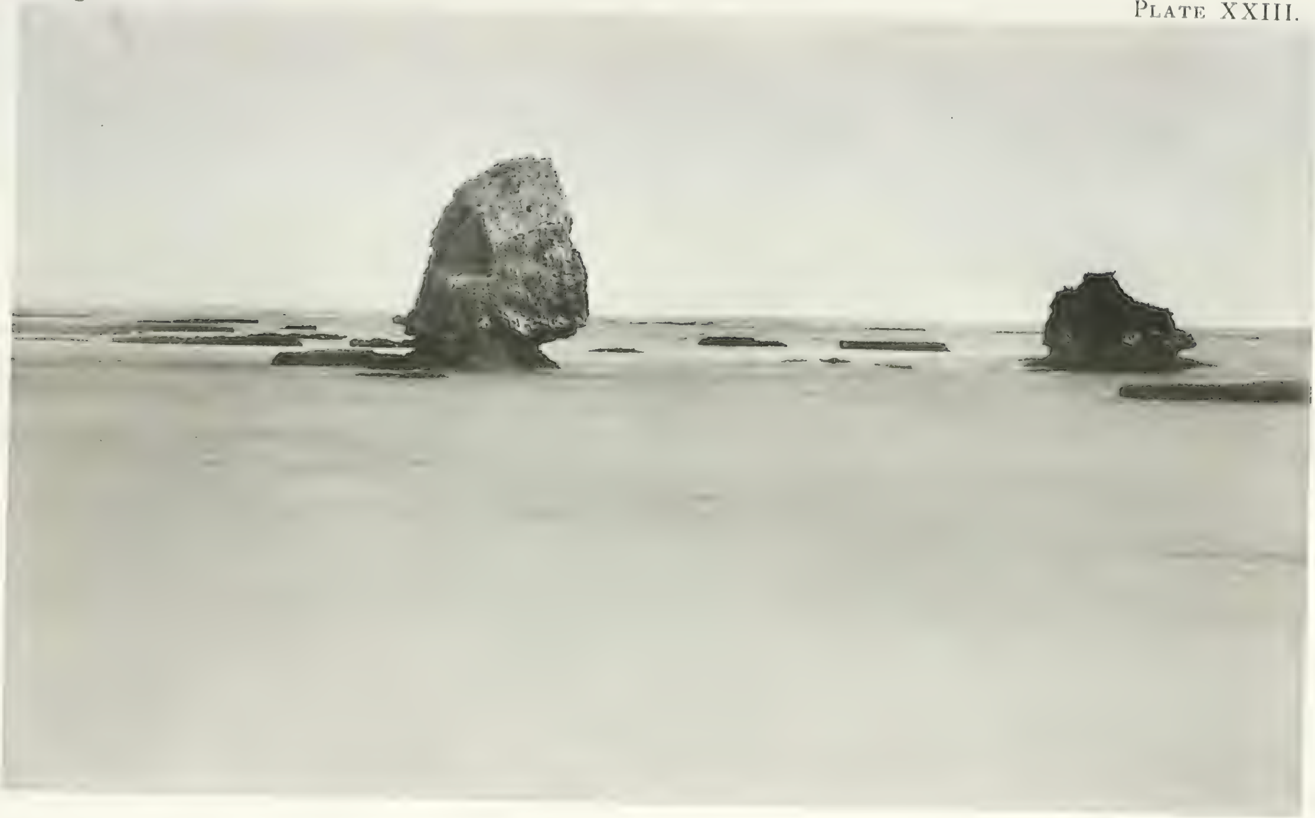
ISLETS OFF CASTLE HARBOR.

PLATE XXII.



ARTOTYPE. E. BIERSTADT, N. Y.

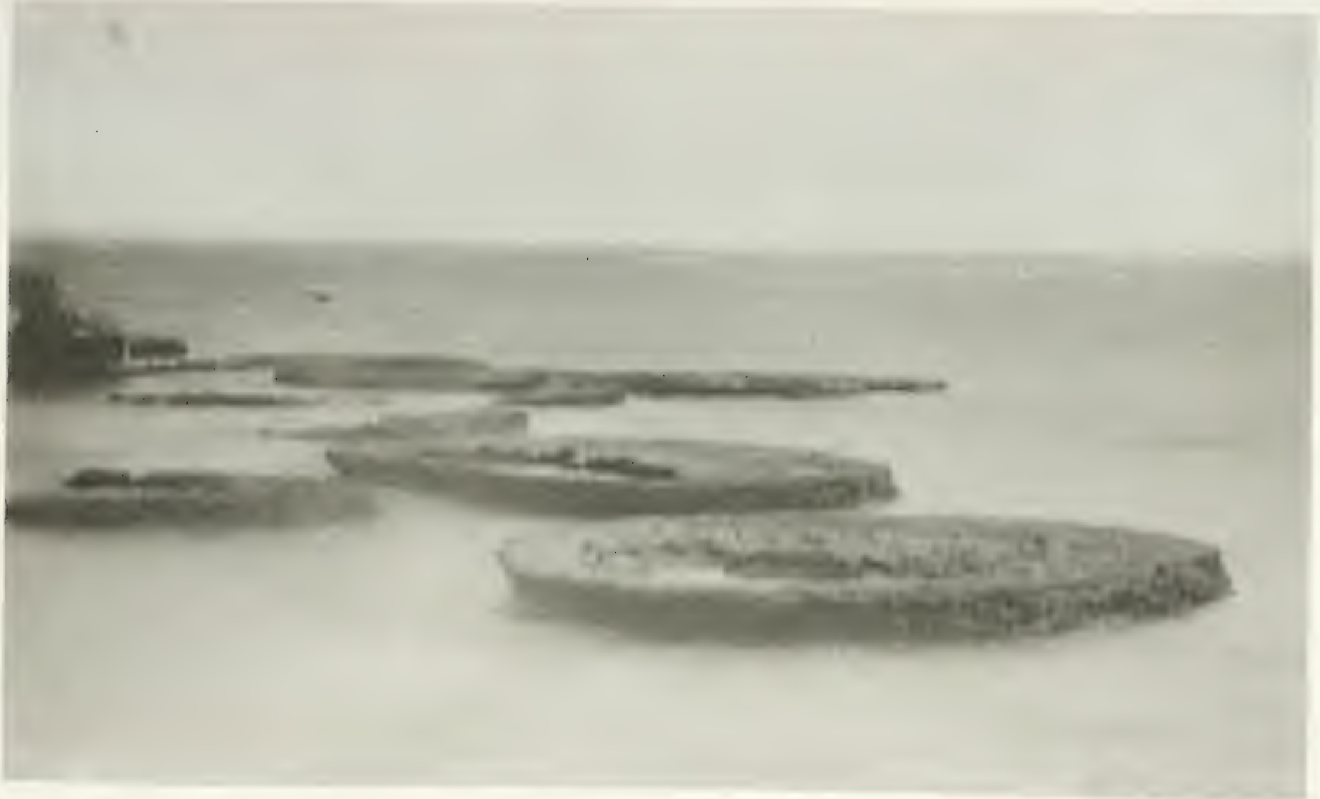
SHORE CLIFFS AND SERPULINE ATOLLS.



ARTOTYPE, E. BIERSTADT, N.

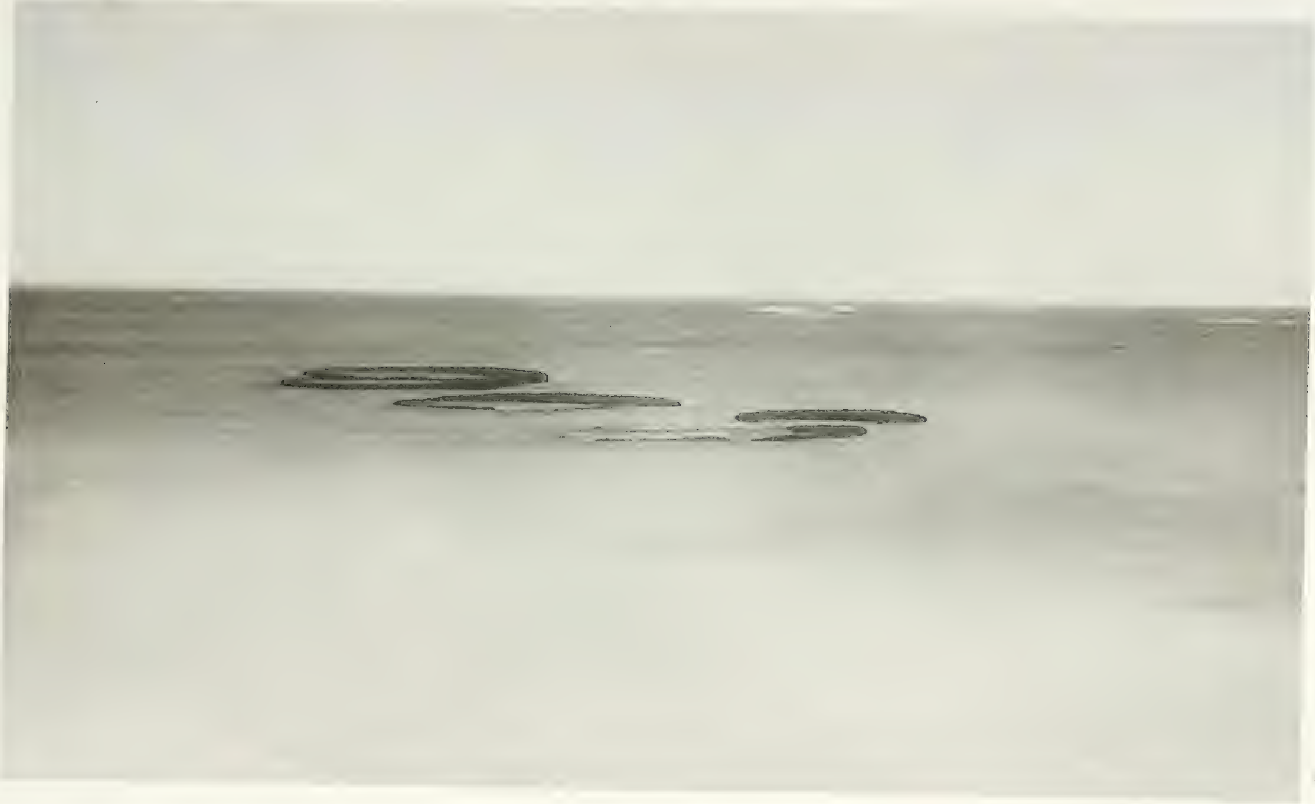
PINNACLES AND SERPULINE ATOLLS.

PLATE XXIV.



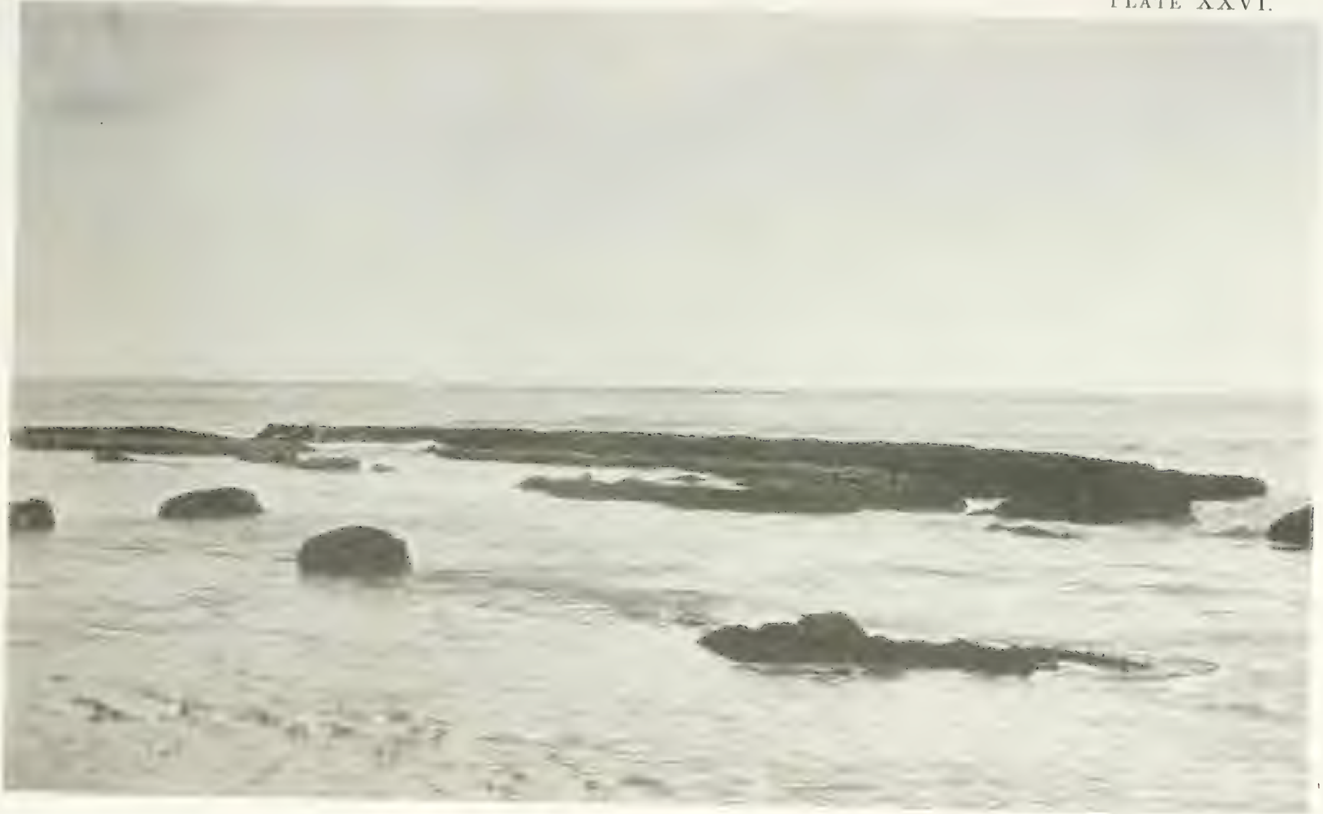
ARTOTYPE, E. BIERSTADT, N. Y.

SERPULINE ATOLLS, SOUTH SHORE.



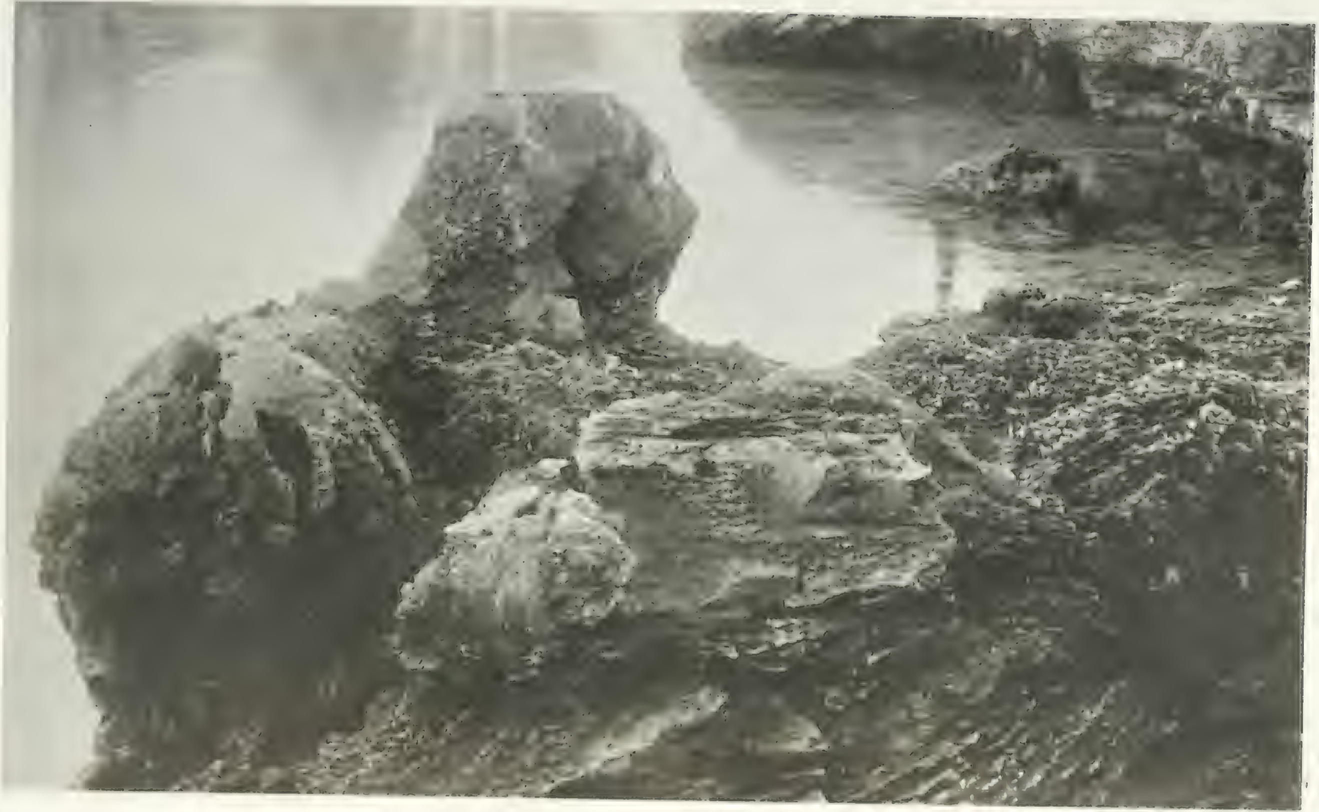
ARTOTYPE. E. BIERSTADT, N. Y.

SERPULINE ATOLLS OFF SOUTH SHORE.



[illegible]

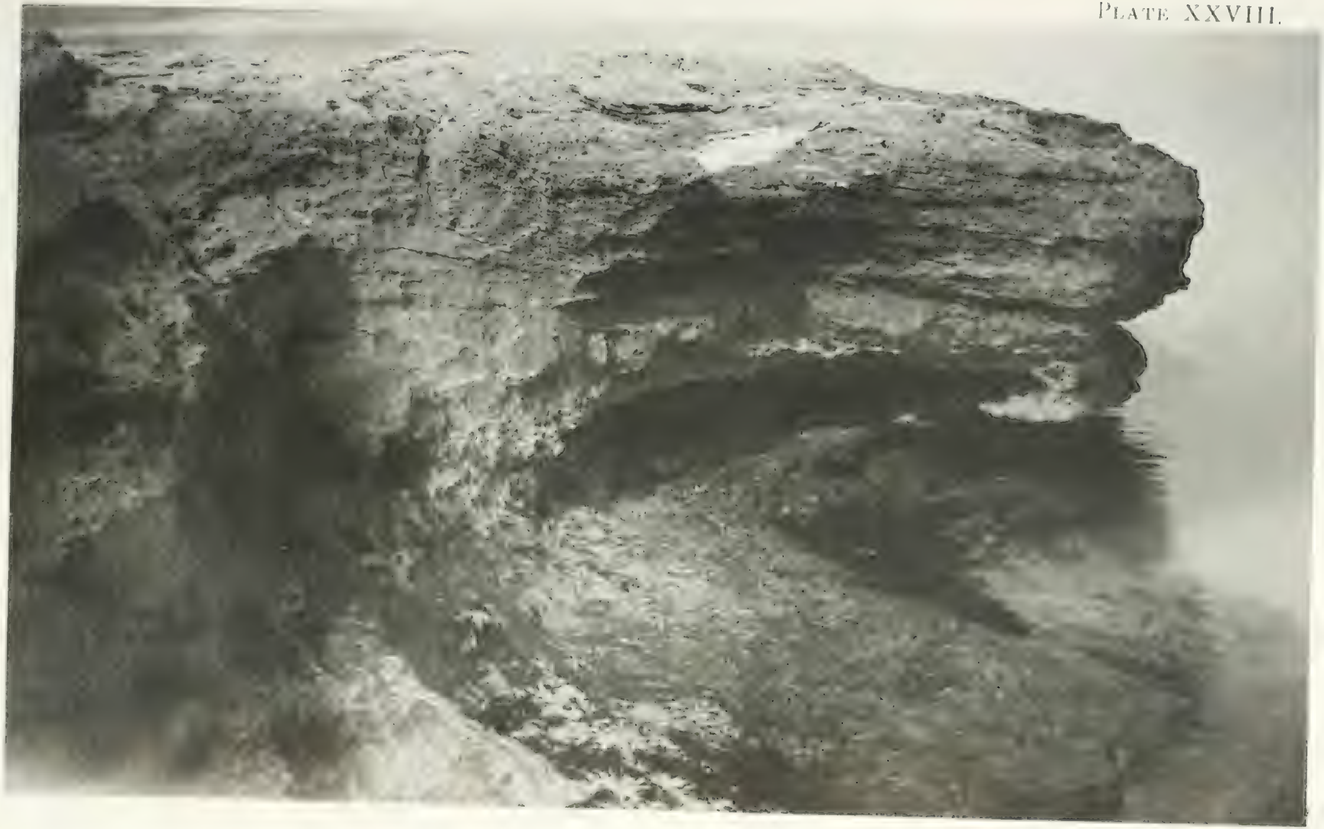
FRINGING SERPULINE REEFS, SOUTH SHORE.



ARTOTYPE, E. BIERSTADT, N. Y.

HONEYCOMBED ÆOLIAN ROCKS, HARRINGTON SOUND.

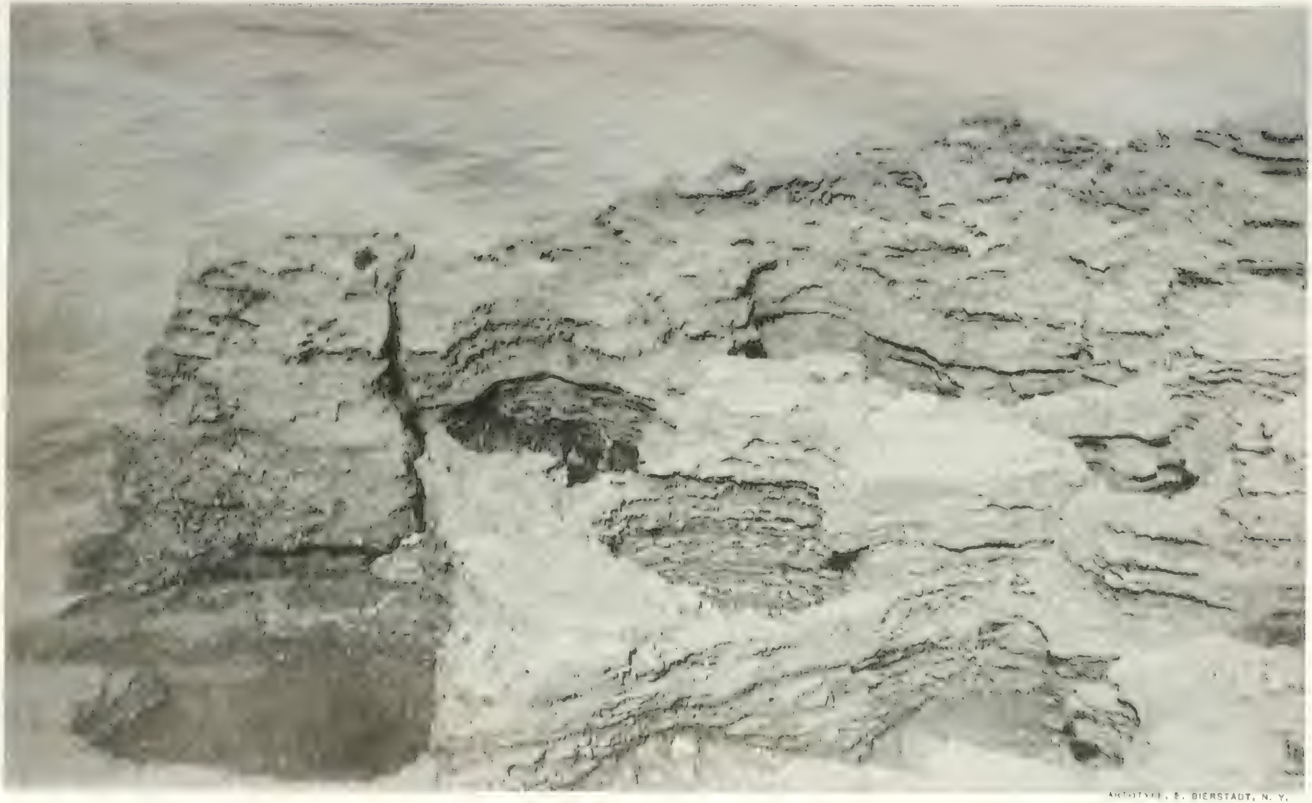
PLATE XXVIII.



ARTOTYPE, E. BIERSTADT, N. Y.

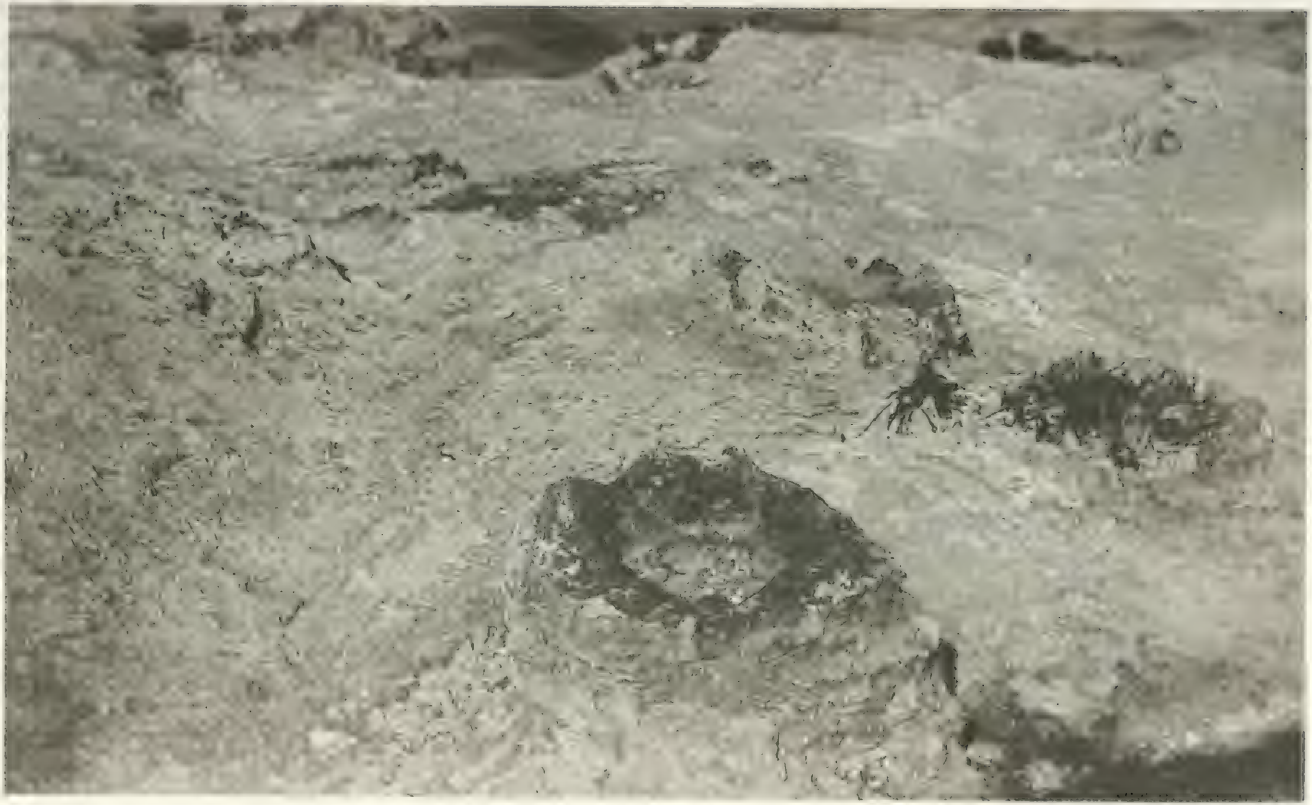
ÆOLIAN ROCKS, NORTH SHORE.

PLATE XXIX.



ARTOTYPE, E. BIERSTADT, N. Y.

POT HOLES, HARRINGTON SOUND.



PALMETTO STUMPS, NORTH SHORE.

# BULLETIN

OF THE

# MUSEUM OF COMPARATIVE ZOÖLOGY

AT

HARVARD COLLEGE, IN CAMBRIDGE.

VOL. XXVII.

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CAMBRIDGE, MASS., U. S. A.
1895–1896.

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# No. 1. — *Spermatogenesis of Caloptenus femur-rubrum and Cicada tibicen.*[1] By E. V. Wilcox.

The following observations were made on the testes of Cicada and Caloptenus. Only three male Cicadæ were at my disposal, but of Caloptenus I examined more than twenty individuals. The Cicadæ were killed immediately after leaving the pupal case, and had been preserved a number of years. The Calopteni were taken in August and September, 1893.

The testes of Cicada were killed in Müller's fluid; those of Caloptenus either in hot water, in hot corrosive sublimate, in cold corrosive sublimate, or in chrom-osmic-acetic mixture. Some of the testicular follicles of Cicada were stained in Grenacher's alcoholic borax carmine, others according to Bizzozero's modification of Gram's method. The follicles were stained *in toto* in safranin (50% alcohol) 24 hours, sectioned, stained 3 minutes in gentian-violet, washed 5 minutes in a solution of potassic iodide, then treated alternately with alcohol and chromic acid (0.1%). But better results were obtained by double staining with safranin and victoria-green. Crystals of the latter were dissolved in absolute alcohol, or in clove oil. The sections were first stained in safranin (10–15 minutes), the excess of stain being quickly washed off in 90% alcohol, and then in a very strong solution of victoria-green in absolute alcohol for 1 to 2 minutes. Staining and dehydrating were thus accomplished at the same time. Excess of green was washed out with absolute alcohol. Sections were cleared in clove oil. When a clove-oil solution of the green was used, the sections were dehydrated before staining in the green. The method with the absolute-alcohol solution gave the better results, and was more easily managed.

The Caloptenus material was all stained on the slide. The methods used were either safranin and victoria-green, as just described, Henneguy's ('91) potassic permanganate and safranin, or Heidenhain's ('92) iron-hæmatoxylin. The method with safranin and victoria-green gave good results. Cytoplasm and achromatic nuclear parts were stained green, the chromosomes, nucleolus, and centrosomes red. If the green be allowed to act too long, it will replace the safranin entirely. This (safranin and green) method was the only one by which the archoplasm was made distinct. The granular cytoplasm was stained green, and in the pale green clear areas of the archoplasm were to be seen the red centrosomes. In *some* stages the chromosomes were stained green, indicating that a chemical change takes place in the chromatic substance. But even in such cases the nucleolus was bright red.

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[1] Contributions from the Zoölogical Laboratory of the Museum of Comparative Zoölogy at Harvard College, under the direction of E. L. Mark, No. XLVII.

In using Henneguy's method, the sections were put into permanganate of potash for 5 minutes, and then stained 3–20 minutes in Zwaardemaker's safranin. The mordant gives an iron-rust color to the sections, and the safranin must not be too much washed out, or the sharpness of outlines will be lost. It is best to wash out the mordant very thoroughly before using the stain, for the potassic permanganate makes a precipitate with the safranin which renders the sections so muddy as to be nearly useless. By this method the chromosomes and nucleoli are stained bright red, the individual chromosomes being sharply outlined. In the metamorphosis of the spermatid, the six spheroidal chromatic elements are often easily distinguished, although closely massed together. The chromatic crescent of the spermatid is very well defined; but the small body in the neck of the spermatozoön, so conspicuous after treatment by Heidenhain's method, is hardly to be seen when this method is used. Centrosomes were rarely stained; achromatic fibres of ring stages were faintly stained; the nucleus often appeared as a clear lenticular space, in which were the red chromosomes.

The best results were obtained by use of Heidenhain's method. The "black" process proved more serviceable than the "blue." The only mordant used was double sulphate of iron and ammonia, $NH_4Fe_2(SO_4)_4$. A 2% aqueous solution was used as mordant, and a 4% aqueous solution as decolorizer. To produce the "blue" stain, the sections were placed in the mordant $\frac{1}{2}$–1 hour, and after washing in water were stained in the hæmatoxylin (0.5% pure hæmatoxylin in $H_2O$) 1–2 hours; finally, they were washed again in water. Sometimes it is necessary to decolorize a short time, say 20 minutes, in 4% $NH_4Fe_2(SO_4)_4$. The "black" stain was obtained by leaving the sections in the mordant 2 hours before washing in water, staining 10–12 hours in the hæmatoxylin, and decolorizing 2–8 hours, finally washing as before. For either process the sections should be very thin. They must be firmly affixed to the slide; for the washing is best done by a stream of tap-water allowed to run over the slide. Three washings are necessary, each of which should be thorough: (1) after use of the mordant,

(2) after staining, (3) after decolorizing. Simple immersion in water does not do as well. The mordant and stain will form a precipitate, just as in Henneguy's method, and if the first washing be neglected, it is next to impossible to remove the precipitate by subsequent washings. One to five minutes in a stream of water is enough for each washing. The sections will become quite opaque immediately after immersion in the decolorizer, but in this the opacity is slowly removed. The decolorization is hastened by washing the sections in water at intervals during the process of decolorizing. This is necessary, also, in order to see how far the decolorizing has progressed. The process can thus be stopped at the desired stage. The proper decolorization is the most difficult part of this method.

By the "blue" process, so far as my experience goes, the cytoplasm stains gray, the centrosomes do not stain at all, the spindle and linin fibres very faintly, the chromosomes dark blue. By the "black" process the cytoplasm takes a dark-gray color, and both centrosomes and chromosomes are made black, while spindle fibres and linin fibres become very distinct. The nucleoli are colored nearly black by either process.

## CICADA TIBICEN.

*The testes of Cicada tibicen* are paired, and each consists of a large number of ellipsoidal follicles, which are closely packed together. The follicles of each side of the body open into a vas deferens, which soon joins its fellow of the opposite side. Figure 14 (Plate I.) gives an idea of the spatial relationship to one another of different spermatogenetic stages. It represents a very nearly longitudinal section of a follicle of Cicada. At *a* are spermatogonia; at *d*, spermatids in various stages of metamorphosis.

The Cicada material at my command did not show the division stages, but it gave a very reliable series of preparations on certain other stages.

*The spermatogonia* lie at the blind end of the follicle. They occupy in my preparations only the single end-compartment (Fig. 14, *a*). Their size is less than that of the spermatocytes, and they are further distinguished from them by the fact that they have only 12 chromatic rods, whereas the spermatocytes have each 24 spherical chromosomes. One or often two nucleoli are to be seen.

*The spermatocytes* occupy usually two compartments next to that of the spermatogonia. The chromatic substance consists of about 24 spheroidal bodies. In Figure 14 the compartment *b* contains spermatocytes of the first order; *c*, spermatocytes of the second order and spermatids just after the last division. (Compare Fig. 23 and Explanation of Figures.) The cells of *b* each contain one or two bodies which I consider nucleoli, since they react to the stains quite differently from the chromosomes. Figures 53–59 (Plate II.) represent cells quite commonly met with among the spermatocytes; they are numbered in the order in which I think they succeed one another. In a single compartment may be found spermatocytes in several different conditions; the earliest seems to be that in which the nucleolus lies in the centre of the nucleus with the chromatic spherules arranged radially about it (Fig. 53). The nucleolus then moves to the periphery of the nucleus, and appears meantime to have divided into two portions (Figs. 55, 56), one of which passes into the cytoplasm, while the other remains in the nucleus (Figs. 58, 59); later, both parts appear outside the nucleus and on diametrically opposite sides of it.

Hertwig ('90) has noticed the disappearance of the nucleoli in the spermatocytes of Ascaris megalocephala just before the appearance of the centrosomes. Brauer ('93) figures the centrosomes as arising singly in each nucleus and dividing either inside (univalens) or outside (bivalens) the nucleus, according to the type. But Brauer saw nucleoli in the same nucleus with the centrosomes and differing from them in stainability. Born ('94) maintains that the nucleoli have nothing to do with either reproduction or cell division. He says: "Die Nucleolen stehen in Beziehung zum individuellen Zellleben, nicht zur Fortpflanzung, denn beim Beginn der Mitose verschwinden sie um nach Beendigung derselben — im Ruhezustand des Kerns — wieder aufzutreten."

Thus the nucleoli have been supposed to give rise to the centrosomes, to be modified chromatin, — a stage in the evolution of a chromosome, — to be excretory organs of the nucleus (Häcker, '93), or to serve some unknown function in the economy of the cell (Born, '94). The nucleoli are found by Born to be very numerous and large in the germinative vesicle of the egg of Triton during the time when the chromatin is inconspicuous; but they disappear entirely before the formation of the first polar globule.

Since there is such disagreement about the origin, function, and fate of the nucleoli, it is probable that different structures have been called nucleoli by different authors. The several bodies in Cicada seen in and near the nucleus in Figures 50 and 53–61 (Plate II.) — in Figures 53, 54, as a single body, in Figures 55, 56, as two bodies, in

Figures 57–59 as two bodies, one of which is outside the nucleus, and in Figures 50, 61, as two bodies, both outside the nucleus — seem to me to give evidence of being stages in the history of one and the same body. My reason for thinking that they are genetically connected is their similarity in size, structure, and reaction to stains.

During the stages shown in Figures 49, 51, 52, there appears to be a chemical change in the constitution of the chromosomes. By the safranin and victoria-green method the chromosomes stain red, though not so deeply as the nucleoli. At later stages the chromosomes assume a green color, while the nucleoli continue to stain red. In still later stages (as Figs. 50, 60, 61) the chromosomes again take the red.

*The metamorphosis of the spermatid* could be worked out in considerable detail. The chromatin is first arranged around the periphery of the nucleus (Plate I. Figs. 24, 27–30). The individual chromosomes fuse into a thin shell of chromatin, surrounding, in part, the nuclear space. This chromatic shell does not extend over the whole periphery of the nucleus, and yet it is so extensive at the beginning of the metamorphosis that in certain views of the nucleus it has the appearance of a complete sphere.

Figures 15–18 and 24–45 show various stages in the spermatid metamorphosis. Figures 62–77 (Plate II.) present a series of the changes which take place in the head of the spermatid. The stage in which the chromatin (Figs. 66–72) has the form of a crescent is very common, and therefore undoubtedly of considerable duration.

The origin of the extranuclear body (Nebenkörper), which is stained dark green in Figures 20, 27–30, could not be determined. On the anterior end of the nearly mature spermatozoön (Fig. 1 *e*) is to be seen a highly refractive curved tip. Just behind it is a small darkly stained body. The body so conspicuous in the neck of the spermatid of Caloptenus (Plate V. Figs. 196–200) was very rarely seen in the Cicada, probably because the methods used on Cicada would not stain it.

*Degenerating cells* are very frequent in the testicular follicles of Cicada. So far as my work on Cicada and Caloptenus goes, amitotic division and degeneration affect only the spermatogonia, i. e. if the reproductive cell reaches the spermatocyte stage, it completes its course. The first sign by which I was able to recognize that a spermatogonium is becoming abnormal is due to a chemical change in the nucleus. The chromosomes stain more brightly than in normal cells. The cytoplasm becomes clearer and more homogeneous. Then the chromosomes become irregular in shape, lose their individuality and fuse into a single mass, as in

Plate I. Figs. 7, 19 (see Explanation of Figures), Plate V. Figs. 204, 210, 211). This mass may be slightly vacuolated and may show nucleoli. Some stages of degeneration in the testes of Caloptenus are shown in Plate V. Figs. 202–220. The nucleus may divide amitotically once, twice, or three times (Figs. 206, 212, 214, 215). This may result in ragged granules or strands, or in regular chromatic spheroids (Figs. 205, 207, 220). It is evident from Figures 202–220, since all are drawn to the same magnification, that some degenerating cells increase enormously in size. These degenerating cells are very numerous in Cicada and Caloptenus, especially in the latter.

In Cicada there are frequently seen spermatozoa and various stages in the metamorphosis of spermatids which are four or five times as large as the corresponding normal forms; they may be called giant spermatozoa. Normal spermatids are represented in Plate I. Figs. 2, 3, 4, 9. Stages in the metamorphosis of giant spermatozoa, drawn to the same magnification, are shown in Figures 12, 13, 21, 22. Figures 78–103 (Plate II.) represent giant spermatid cells found accompanying normal cells. Figure 104 shows normal spermatids, the magnification being the same as in Figures 78–103. The striking similarity between the corresponding stages of a normal spermatid and giant forms is very readily seen on comparing Figures 62–77 with Figures 78–86. The first series is much more highly magnified than the second, hence the apparent equality of size.

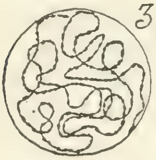
Figures 202, 203 (Plate V.) represent the only examples found in Caloptenus which resemble the giant spermatozoa of Cicada.

What is the meaning of giant spermatozoa? Frenzel ('91, '91$^a$), Löwit ('91), vom Rath ('90, '91, '93), Verson ('91), Ziegler ('91), Ziegler und vom Rath ('91), Flemming ('89), Geberg ('91), and Meves ('91), have discussed the question of amitotic division, *Lochkerne*, *Ringkerne*, and other degeneration conditions. I believe with vom Rath ('93), that "Alle Zellen welche einmal amitotische Kernteilung erfahren haben, können sich unter keiner Bedingung mehr mitotisch teilen, sie gehen vielmehr einem sicheren Untergang entgegen." I believe that the giant spermatozoa are not functional, that they are excluded from the developmental series and really come to naught. But they arise in Cicada directly from spermatogonia without cell division, by a metamorphosisis of the nucleus, which may or may not be accompanied by amitotic division of the nucleus. In such spermatogonia the nuclei may divide amitotically two or more times (Fig. 8). Then, in the majority of cases, the chromatin breaks up into numerous fragments, which are scattered about the cell irregularly after the nuclear membrane degenerates. Or the fragments may fuse into one mass, which subsequently breaks up. But quite often in Cicada the metamorphoses of these nuclei are rather regular, presenting stages very similar to those which the normal spermatid undergoes. I am not aware that any one hitherto has suggested that the giant spermatozoa arise directly from spermatogonia, and *a priori* it seems, I admit, quite improbable; yet my Cicada preparations point very strongly to this conclusion.

## CALOPTENUS FEMUR-RUBRUM.

The testes of Caloptenus consist of tubular follicles, which lie closely packed together, parallel to one another. They are of nearly the same size throughout their length, being slightly larger near the blind end of the tubule, and tapering thence into the collecting duct, which opens into the vas deferens. In my Caloptenus material, taken in August and September, the spermatogonia were confined to a single compartment at the blind end of the tubule. After the spermatogonia the other stages follow in regular succession, a considerable part of the follicle being occupied by the prophases of the first division of the spermatocytes. Then follow regions in which the two successive cell divisions are taking place, then the spermatid metamorphosis, and finally the nearly mature spermatozoa, which with the degenerating cells entirely fill the lumen of the tubule. Figure 108 (Plate III.) represents a longitudinal section of a follicle, in which spermatogonia are shown at *a*, prophases of the first spermatocyte division at *b*, the first division at *c*, spermatids at *d*, immature spermatozoa at *e*, and degenerating cells at *f*. The stages of spermatogonia preparatory to division are seen in Plate III. Figs. 105–107, and Plate IV. Figs. 164–168. Spermatogonium divisions are shown in Plate III. Figs. 119–121, 124, 131, 138, and Plate IV. Figs. 169–171, and a tripolar division at Plate IV. Fig. 189. I could not determine how many divisions the spermatogonia undergo. The chromosomes in the prophases are twelve in number, twenty-four at the equator of the spindle, during metakinesis. The individual chromosomes are rod-shaped or often elongate spindle-shaped. In metakinesis they show ordinarily the well known **V**-shaped figures, and are connected with each other in pairs by means of linin fibres. The centrosomes are usually apparent (Plate III. Figs. 105, 132). Figure 105 shows the centrosome surrounded by a clear protoplasmic area. In most cases a nucleolus is to be seen during the prophases. In Figure 106 there is in the nucleus a body (nucleolus?) which seems to have recently divided.

Before describing the history of the spermatocytes, I will call attention briefly to the figures which illustrate their various conditions. The earliest stage of spermatocytes that I have found is shown in Plate III. Figs. 110, 111. In Figure 111 the cell is not complete, part of the chromatin having been cut away in the previous section. Figure 221 (Plate V.) is of about the same age. Figures 114, 116 (Plate III.), and 184–186 (Plate IV.) give an idea of a slightly older stage. Figures 187, 188 (Plate IV.), and 222 (Plate V.) are still older. In these the chromatic thread is already broken up into segments. Figures 228, 229, 242, 243 (Plate V.), and 175, 176, 178 (Plate IV.), show various stages in the ring and "Vierergruppen" formation. During the first spermatocyte division the chromatic Vierergruppen are arranged at the equator of the spindle, essentially as shown in Figure 175 (Plate IV.). Figures 237–241 (Plate V.) illustrate the first division of the spermatocytes.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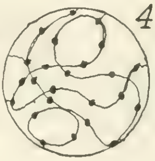
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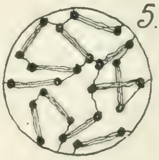
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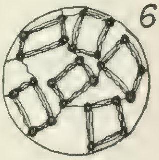
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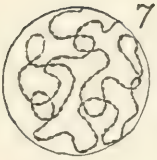
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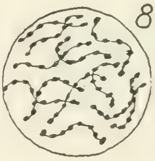
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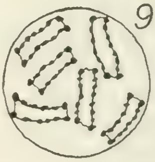
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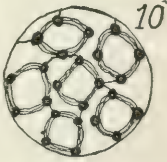
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The history of the spermatocytes of the first generation is as follows. (Compare Diagrams 3 to 6 and 7 to 10.) In the earliest prophase that I have seen (Plate III. Figs. 110, 111) the chromatic substance consists of numerous small granules, already arranged along a thread of substance, which itself stains somewhat (Diagram 3). The chromatic granules gradually become collected at twenty-four points on the thread (Diagram 4). The thread then breaks transversely into twelve segments (Diagram 5). Each of these segments has the form of a dumbbell, i. e. consists of two terminal chromosomes connected by a thread, composed of numerous linin fibres (Plate IV. Fig. 187, Plate V. Figs. 242, 243).

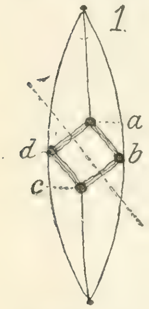
The dumb-bell figures become associated in pairs (Plate V. Figs. 229, 242, 243). Each of the six groups (Diagram 6) thus formed has the value of four chromosomes, each dumb-bell being equal to two chromosomes (Plate IV. Fig. 178, Plate V. Figs. 242, 243). These quadrivalent groups may be formed by the approximation of the pairs of dumbbells in one or the other of two ways. Either they become arranged quite irregularly (Plate III. Fig. 116, Plate V. Fig. 229), or the pairs may at first lie across each other at right angles, and later come to be parallel (Plate V. Figs. 229, 242, 243). A comparison of the drawings last mentioned will show how by the fusion of the ends of the two parallel dumb-bells a ring results, such as is shown in Plate IV. Figs. 178, 179, 181.

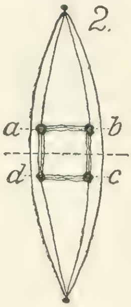
By a slight variation in the time at which the massing of the chromatin granules takes place the process up to this point may pursue a course apparently quite different from that described. The chromatin granules of the original chromatin thread do not become massed into definite chromosomes as early as in the method just outlined. Consequently the transverse divisions result in the formation of twelve segments (Diagram 8) with very irregularly serrated edges. These segmenta associate themselves (Diagram 9) in pairs (Plate V. Figs. 201, 225, 227). They are either so closely applied to each other as to appear like single rods, or else show two rows of granules (Fig. 227), and thus give the same appearance that would have resulted from a longitudinal splitting of a single segment. The component halves of these six segments separate from each other except at their ends, and thus form rings, as in Plate IV. Fig. 174. The granules scattered along these rings then collect into four chromosomes (Diagram 10). The result is, therefore, the same as by the process first mentioned.

This account of the formation of rings varies somewhat from those of vom Rath ('93) and Häcker ('93), and is entirely different from Brauer's ('93) account. These differences, as well as the points of agreement, will be discussed under the literature of the subject.

The position of the chromatic rings at the equator of the spindle is shown in Plate V. Figs. 192–195 and 237–241. The rings are always complete at this stage, and the first step in the metakinesis of the spermatocytes consists in a separation of the rings into half-rings. With the iron-hæmatoxylin method the majority of the spindles present the appearance of Figures 194, 195. The planes of the rings all pass through the axis of the spindle. Hence it is impossible to see that the chromosomes are arranged in rings, except when the rings are turned broadside toward the observer, as sometimes happens (Figs. 237–239). Figure 192 shows four rings seen from the edge and two from the side. The four chromosomes of a group may be arranged in a square rather than in a circle (Plate IV. Figs. 175, 176).

The division of the rings may present different appearances according to the position of the chromosomes with reference to the poles of the spindle. The group may be a square, with one side turned toward each pole of the spindle (Diagram 2), or it may be more diamond-shaped (Diagram 1) with an angle directed toward each pole. In either case division takes place as indicated by the dotted line, and the chromosomes *a* and *b* go to one pole, *c* and *d* to the other. The final result, therefore, is the same as before. But in the first case the chromosomes *a* and *b*, still held together by linin threads, move toward the pole maintaining unchanged their relative positions, i. e. the rod with a chromosome at either end remains at right angles to the polar axis of the spindle, and is therefore in proper position for the second division, which follows directly upon the first, and is at right angles with it, *a* going to one spermatid, *b* to the other. By the second mode the pair *a*, *b* starts for the pole, either in a very oblique position or nearly parallel to the polar axis, and with *a* in advance. It therefore must turn 45° or more so as to be in the proper position for the second division.





The later stages of the first spermatocyte division are shown in Plate III. Figs. 112, 113, 117, 118, 122, and 123, which are drawn from preparations stained with safranin and victoria-green, or by Henneguy's method. These methods do not bring out the individual chromosomes at this stage. Figures 118 and 122 show the interzonal filaments still bridging over the space between the already separated cells. Some cells at this stage (Figs. 113, 117) have a peculiar appearance, as if the division were amitotic. But the interzonal filaments between the two chromatic masses show it to be a mitotic division.

The second division of the spermatocytes is shown in Plate III. Fig. 128, and Plate V. Figs. 190, 191, 231. This division is accompanied by the formation of a typical spindle and centrosomes; it effects a separation of the constituent chromosomes of each chromatic dumbbell, and therefore results in giving each spermatid six univalent spherical chromosomes, such as are shown in Plate III. Figs. 125, 126.

The number relationships of the chromosomes in the spermatogenesis of Caloptenus may be thus tabulated: —

| | |
|---|---|
| Spermatogonia | 12 univalent chromosomes. |
| Spermatocytes, 1st order | 6 quadrivalent chromosomes. |
| Spermatocytes, 2d order | 6 bivalent chromosomes. |
| Spermatids | 6 univalent chromosomes. |

Expressed in individual chromosomes: —

| | | | |
|---|---|---|---|
| Spermatogonia | 12 | Spermatocytes, 2d order | 12 |
| Spermatocytes, 1st order | 24 | Spermatids | 6 |

Spermatids immediately after the second spermatocyte division are shown in Plate III. Figs. 125, 129, and Plate V. Fig. 232. There is at first no nuclear vacuole surrounding the six small spherical chromosomes, which are closely packed together, and immediately surrounded by the granular cytoplasm (Plate III. Figs. 125, 126, 129). The interzonal filaments are still to be seen, forming a striated body, probably the beginning of the "Nebenkern," as suggested by Platner ('86).

Some of the spermatids stained by Henneguy's method, and nearly all of those stained by Heidenhain's method, show a spherical body near the chromatic mass (Plate V. Figs. 232–235), and this body becomes included in the nuclear vesicle when a membrane is formed (Plate IV. Figs. 140, 141, Plate V. Figs. 232, 236). I regard this body as the centrosome which is left in each spermatid after the last spermatocyte division, and I also believe it to be identical with the very conspicuous body which forms the neck of the spermatozoön (Plate V. Figs. 196–200). The chromatic substance fuses into a smoothly contoured mass, which soon assumes the crescent shape so common in insect spermatogenesis. The neck-body lies within the nuclear membrane opposite the concavity of the chromatic crescent (Figs. 198–200). The chromatin undergoes chemical and physical changes during the metamorphosis of the spermatid, but the neck-body remains practically the same in size, and does not alter its affinity for stains. It becomes the neck of the spermatozoön (Plate IV. Figs. 139–158, Plate V. Figs. 196–200). The chromatic crescent is at first less dense, and stains less deeply; then it becomes concentrated, and stains nearly black by Heidenhain's method. These changes in density are not well shown in the figures. At the same time it becomes elongated, one end applying itself to the neck-body, the other becoming the tip of the spermatozoön head.

The nuclear vacuolation, much reduced, persists for some time near the neck-body (Fig. 196), then disappears entirely, and the further metamorphosis of the head consists largely in an elongation. By Henneguy's method the neck-body is only rarely stained. This explains its absence in Figures 142–154. By Heidenhain's method it becomes in all spermatids a very conspicuous black spherical body (Plate V. Figs. 196–200).

I pass now to a consideration of the results reached by other students of spermatogenesis in insects.

Sabatier ('90) has discussed in a short article the spermatogenesis of the Locustidæ. The conclusions to which he comes are rather startling. In regard to the metamorphosis of the spermatid, he says: "Près du noyau mais non à son contact immédiat apparait dans le protoplasme une vésicule sphérique . . . la vésicule protoplasmique." Sabatier maintains that there is an almost total degeneration of the nucleus, but admits that it gives rise to the "Kopfkappe": "Cette dernière dérive donc du noyau et fournit un exemple remarquable de la dégénérescence ou altération du noyau de la cellule spermatique." It is quite remarkable that the nucleus is able to form only the Kopfkappe when, presto, "cette vésicule devenue fusiforme et vivement colorable constitue ce que l'on considère comme la tête du spermatozoïde."

I have never seen any such nuclear degeneration, nor any extranuclear vesicle of such paramount importance. The head of the Caloptenus spermatozoön arises from the six chromosomes inherited by each spermatid.

Blochmann ('87) describes the formation of the polar bodies in Blatta germanica.

The work of vom Rath ('91ª and '92) on the spermatogenesis of Gryllotalpa must receive special notice. My account of the spermatogenesis of Caloptenus confirms a large part of vom Rath's results, but differs from his in several points, and suggests another interpretation of the last two divisions. What these differences are will soon be apparent.

Vom Rath ('93) has already called attention to the many groups of animals in whose spermatogenesis or oögenesis ring formation and Vierergruppen have been observed by different authors; but with one exception (Flemming, '87) he mentions those authors only who have noticed and remarked about these chromatic figures. It may seem venturesome, but I wish to suggest the same interpretation for the figures of various authors who either had no definite idea of Vierergruppen, or considered the conditions exhibiting them abnormal (Flemming, '87), and were thus unprejudiced in favor of rings or Vierergruppen in making their drawings. The older works will be mentioned first, and the important works of Boveri ('90), Brauer ('93, '94), Häcker ('93), Henking ('90, '91, '92), and vom Rath ('91[a], '92, '93), will be considered later.

Flemming ('87, pp. 444, 445) saw Vierergruppen in the Salamander. Figures 46–50 of his paper show chromosomes arranged in groups of four, the groups being scattered quite irregularly over the spindle, much as vom Rath figures them in his latest paper ('93). Flemming considered this arrangement as abnormal: "Sie [the grouping into fours] kann wohl in der That als eine Anomalie bezeichnet werden, obwohl ich noch nichts darüber weiss ob aus den Folgestadien etwas normales werden kann oder nicht, . . . es finden sich also Gruppen von je vier Kügelchen von denen je zwei aneinanderhängen. Diese liegen anscheinend ganz regellos über die ganze Spindel hingestreut, nur offenbar mit der Tendenz sich nach den Polen anzuhäufen." Vom Rath calls attention to Flemming's explanation of these figures, and holds, quite rightly, that the groups are moving, not as Flemming imagined, toward the poles, but toward the equator, there to be separated into bivalent dumb-bells. Flemming believes he finds a tendency to irregularity in those spindles which bear four-grouped chromosomes, and considers such irregular spindles as so many stages in the degeneration of a bipolar spindle into a tripolar one. If with Flemming it is denied that the groups of four occur in the regular course of development, it must be concluded that these are degeneration stages.

Platner ('86) has figured in Helix pomatia several stages of rings and their division without so interpreting them. Figure 4 of his article "Ueber die Entstehung des Nebenkerns," etc., shows very clearly the ring condition previous to division. In his Figure 5 are groups of four chromosomes. Figure 12 shows rings on the equator of a spindle, and Figures 15–17 are metakinetic and dyaster stages, in which the spherical chromosomes are coupled into dumb-bell figures and some of the dumb-bells have rotated 90° and are ready for the second division, just as I have seen them in Caloptenus.

I would call attention also to the following cases drawn from the literature of the subject: La Valette St. George ('85, Figs. 16, 17, '86, Figs. 11, 21, 22), Zacharias ('87, Taf. VIII. and IX.), Kultschitzky ('88, Fig. 3, and '88[a], Figs. 16, 17, 22), Carnoy ('85, '86, and 86[a]), Guignard ('91), Baranetzky ('90, Figs. 23, 26, 40), Hermann ('89, Fig. 31), Lukzanow ('89, Figs. 21, 23), Henking ('92, Figs. 101, 153, 190, 216, 217, 229, 413, 418), Stuhlmann ('86, Figs. 228, 233), and Moore ('93, Fig. 1).

The terminology which I have used is that of La Valette St. George, as adapted by Boveri : —

Spermatogonium = Hertwig's Ursamenzelle.
Spermatocyte, 1st order = " Samenmutterzelle.
Spermatocyte, 2d order = " Samentochterzelle.
Spermatid = " Samenenkelzelle.
Spermatozoön.

G. W. Field ('93) uses a terminology which seems to admit one less spermatocyte stage than is recognized by *authors generally :* "We find that the largest cells, the spermatogones (using the nomenclature proposed by La Valette St. George and now very generally adopted), divide by mitosis and form two spermatocytes. Next each spermatocyte divides, *also by mitosis*, forming two spermatids. Each spermatid then changes directly into the spermatozoön, without further division. Thus each spermatogone gives rise to four spermatids." Field uses this apparently as a general scheme of spermatogenesis. "Spermatogones" are, I suppose, spermatogonia. But they are not "the largest cells" in Boveri's scheme, nor do I find that La Valette St. George or any other author has applied the term to these large cells, which Boveri designates as spermatocytes of the first order. The spermatogonia after they have ceased dividing as spermatogonia become by a process of growth spermatocytes (Boveri's spermatocytes, 1st order). Field's "spermatogones" therefore probably correspond to Boveri's spermatocytes of the 1st order, his "spermatocytes" to Boveri's spermatocytes of the 2d order, and the spermatogonia of Boveri are unmentioned. Field has therefore extended the use of the term spermatogonia to cover the whole period of that cell generation which Boveri calls at its beginning the last generation of spermatogonia, and during the rest of its existence spermatocytes of the first order ; consequently he designates as a *spermatogonium division* one that Boveri calls a *spermatocyte division.* It is difficult to see why the fact that "each spermatocyte divides *also by mitosis*" need be so strongly emphasized. It would be much more strange if the spermatocytes divided amitotically (compare vom Rath '91 and '93, and Ziegler '91).

Henking ('91) in his paper on Pyrrhocoris has considered the origin and fate of the chromatic rings. His Figures 13–20 show stages in the formation of the rings. Henking differs from most other authors in denying that there is any doubling of the chromosomes between the last division of the spermatogonia and the first division of the spermatocytes. He maintains that the first division of the spermatocytes is a reduction division and the second an equation division. His number relationships for the chromosomes are hence the following: —

| | |
|---|---|
| Spermatogonia | 24 |
| Spermatocytes, 1st order, 12 *bivalent rings* | 24 |
| Spermatocytes, 2d order | 12 |
| Spermatids | 12 |

The only reference by Henking to rings of the value of four chromosomes is in this sentence: "Ich mache besonders auf die mit vier Verdickungen versehenen Ringe 1 und 2 in Fig. 20 aufmerksam." The two rings to which Henking refers contain each four nearly spherical chromosomes, and these, I believe, are the only instances in which Henking recognized the real value of chromatic rings. Each ring contains four chromatic elements, each half-ring two elements, and since these two elements are separated from each other at the second spermatocyte division, this, contrary to his conclusion, is just as truly a reduction division as is the first. But Henking objects to this interpretation: "Es findet hier also keine Reduction statt, sondern eine gewöhnliche Aequationstheilung, welche jedoch hier schon von fernher vorbereitet war." But if each ring has the value of four, not simply two, chromosomes, the same argument could be applied to the first as well as the second spermatocyte division, as Brauer ('93) has already done. The soundness of these objections will be considered in connection with Brauer's paper.

Häcker ('92$^a$ and '93) has seen ring formation and Vierergruppen in the oögenesis of several marine Copepods. In the genera Euchæta, Calanus, Cyclops, Diaptomus, Canthocamptus, and Heterocope, he maintains that "zwischen die letzte Theilung der Ureizellen und die erste Theilung der Reifungsphase ist kein feinfadiges Ruhestadium des Kernes (Keimbläschenstadium) eingeschaltet." In the eggs of some females this resting stage is passed over, in others not. In those females in which the resting stage in oögenesis is twice omitted, i. e. both before and after the formation of the first polar globule, Häcker ('92) suggests, as a motive for the omission of the first resting stage, that in this way "im Mikrokosmus des regenerativen Lebens eine weitgehende Anpassungsfähigkeit zur Geltung gelangt." This omission, then, is a biological adaptation. The maturation of the egg is thus brought about sooner. This explanation is mentioned, because it has a direct bearing upon any interpretation of the rings, as will soon be seen. Häcker

('93, pp. 462, 463) describes the formation of the Vierergruppen as follows: "Die eigentliche chromatische Substanz konzentriert sich nämlich zunächst auf bestimmte Stellen der Doppelfadenschlinge, und an jeder dieser Stellen tritt mehr und mehr eine scharfe Knickung hervor (Fig. 15 *a*, 16 *a*), durch welche diese Doppelfadenpartieen je in zwei gleiche Schenkel getheilt werden. . . . In einem weiteren Stadium findet eine tropfenförmige Verdickung der 4 Enden der Doppelschenkel statt (Fig. 16 *b* und *c*), in den Ecken der Doppelwinkel kommt es dann zur Zerlegung derselben (Fig. 16 *d*), die vier Schenkel verkürzen sich noch mehr und das Resultat dieser Veränderungen sind demnach Bündel von je vier kurzen dicken Stäbchen, welche in der oben angegebenen Weise durch feine Doppelfäden mit den Nachbarbündeln verbunden sind. Es sind die charakteristische Vierergruppen welche immer wieder und wieder vor der ersten Theilung der Reifungsphase auftreten." Häcker's theoretical explanation of the Vierergruppen may be learned from the following: "Wenn wir unter einem Paar von Schwesterelementen ['identischen Idanten,' Weismann '91] solche Elemente verstehen welche durch Längsspaltung eines Mutterelementes entstanden sind, so besteht also jede Vierergruppe aus zwei Paaren von Schwesterelementen welche im zusammenhängenden Doppelfaden ursprunglich hintereinander gelegen sind." Häcker ('92) had previously, in considering the longitudinal splitting of the chromatic thread in the prophases of the first division, treated this as a process by itself, and so had regarded both polar-body divisions as reduction divisions. But later he came to view this splitting as a precocious preparation for the formation of the first polar body, or rather as a process pushed back in time by the subsequent introduction of a germinative-vesicle condition. He now ('93) sees in the first division a *modified* equation division: "Um zu beweisen dass die erste Theilung eine modificierte Aequationstheilung ist, müssten wir zeigen dass ihr eine einmalige Längsspaltung vorangeht durch welche die Normalzahl der Elemente verdoppelt wird, und dass dann bei der Theilung die so erzeugten Schwesterelemente auseinandertreten."

Häcker's conclusion with regard to the Vierergruppen is, in his own words: "Heissen die im Chromatinfaden hintereinanderfolgenden Idanten *a*, *b*, *c* . . ., so würde der längsgespaltene Chromatinfaden sich nach Weismann durch $\left\{\begin{matrix} a\ b\ c\ .\ .\ . \\ a\ b\ c\ .\ .\ . \end{matrix}\right\}$ darstellen lassen, und die Formel für eine Vierergruppe ist: $\left\{\begin{matrix} a\ b \\ a\ b \end{matrix}\right\}$. *Jede Vierergruppe besteht also im*

*Sinne Weismann's aus zwei Paaren von Schwesterelementen* und nicht, wie dies nach Boveri's und Brauer's Angaben der Fall sein würde, aus vier Enkelelementen $\left(\left\{\begin{matrix} a\ a \\ a\ a \end{matrix}\right\}\right)$."

The separation of the sister elements, which according to Häcker occurs in the first division, constitutes an equation division, and "In der zweiten Richtungstheilung erfolgt dann die definitive Trennung der nichtidentischen Idantenpaare." Therefore, the second division alone is a reduction division.

Vom Rath ('91$^{a}$, '92, '93) has in two important papers discussed the formation of rings and the meaning of the Vierergruppen in connection with the question of reduction. Häcker and vom Rath agree in all essential points as to the origin of the rings, as can be seen from the following quotation from vom Rath's last paper: "In allen von mir untersuchten Fällen der Spermatogenese und Ovogenese entstehen die Vierergruppen vor der Reifungsperiode in gleicher Weise dadurch, dass im Knäuelstadium zwei hintereinander gelegene Segmente mit einander verbunden bleiben und mit den durch die Längsspaltung des Chromatinfadens entstandenen ebenfalls verbundenen zwei Schwestersegmenten eine bald innigere (Ringbildung) bald losere (keine Ringbildung) Zusammengehörigkeit bewahren. Aus jedem dieser vier Segmente entstehen dann durch Kontraction vier Stäbchen — oder Kugelchromosomen. Es scheint mir daher das Natürlichste zu sein, jede Vierergruppe als aus vier Einzelchromosomen bestehend anzusehen." Häcker's account, as previously quoted, is strikingly similar to this. Vom Rath evidently meant to say that out of each of the four segments arises by contraction *one* spherical chromosome, *not four*. If four chromosomes arose from *each* of the four segments, we should have groups of sixteen.

Vom Rath inclines to the belief that both maturation divisions are reductions: "Wieder andere, nämlich Weismann, Häcker und ich, lassen die Reduction durch beide Theilungen erfolgen." He adopts Häcker's formula $\left(\left\{\begin{matrix} a,\ b \\ a,\ b \end{matrix}\right\}\right)$, quoted above, for the Vierergruppen. The scheme of numbers of chromosomes, exactly the same as that of Häcker, is as follows: —

| For Gryllotalpa. | For Salamandra. |
|---|---|
| Spermatogonia, 12. | 24. |
| Spermatoc. 1st order, 6 rings, 24 chromosomes. | 12 rings = 48 chromosomes. |
| Spermatoc. 2d order, 6 half-rings, 12 " | 12 half-rings = 24 " |
| Spermatid, 6 chromosomes. | 12 chromosomes. |

The number of chromosomes in the spermatocytes of the first order is thus double the normal number, and this is reduced to one half the normal number by two reduction divisions (vom Rath, '92 and '93).

Brauer ('93) in studying the spermatogenesis of Ascaris has come to some quite definitely stated conclusions in regard to the meaning of the reduction of the chromatin, which can be made clear by a few quotations: —

"Es ist zwischen beiden [spermatogonia and spermatocytes] ein echtes Ruhestadium des Kerns vorhanden, von einem Fortbestehen der Chromosome der Spermatogonien kann keine Rede sein."

"Es bedarf kaum einer näheren Auseinandersetzung, dass diese Ansicht sich mit der Individualitätshypothese der Chromosome . . . nicht verträgt. Die Chromosome sind für mich keine selbständigen Individuen, sondern sie sind nur die Verbände für die zahllosen kleinen Chromatinkörner, welchen allein der Werth eines Individuums zukommt."

"Ist meine Ansicht über die Bedeutung der Chromosome richtig, so erfolgt bei diesen Theilungen keine Reduction der Zahl der Chromatinkörner, sondern nur eine solche ihrer Masse. Eine Reductionstheilung im Sinne Weismann's findet mithin nicht statt. Eine solche dürfte meiner Ansicht nach überhaupt unmöglich sein, wo wenigstens die Theilung auf karyokinetischem Wege erfolgt." A like conclusion is reached for the *centrosomes*: "So müssen dieselben bei der Befruchtung in irgend einer Weise eine Reduction ihrer Masse erleiden, da sonst eine stete von Generation zu Generation fortschreitende Vergrösserung eintreten müsste."

Speaking of the longitudinal splitting of the chromatin granules, he says: "Da diese Theilung aber das Wesen der ganzen Karyokinese ausmacht, so halte ich alle diejenigen Erscheinungen welche ihr folgen, wie das Ansammeln der Körner auf wenigen Fäden, ihre Vereinigung zu grösseren Körnern, der Zerfall eines Fadens in Segmente und schliesslich in Chromosome, für weniger bedeutend." Briefly, Brauer does not believe in any reduction division in the Weismannian sense of the term, but only in a reduction of the *mass* of the chromatin.

Thus there have been proposed by different authors four different solutions of the question of reduction. Henking holds that the first maturation division is a reduction, the second an equation division; Hertwig considers the first an equation and the second a reduction division; Brauer maintains that there is no "reduction" in either division (except in mass), whereas Weismann, Häcker, and vom Rath maintain two reduction divisions. But Häcker ('93) now calls the first a "modified equation" division, and only the second a reduction division.

I have used the word "reduction" without indicating the particular sense in which I use it. The definition of reduction proposed by Weismann ('92), and adopted by vom Rath, Häcker, and others, is that which I prefer, and according to which I have used the term. This is: "Unter Reductionstheilung verstehe ich eine jede Kerntheilung durch welche die Zahl der Ide welche im ruhenden Kern vorhanden war, für die Tochterkerne auf die Hälfte herabgesetzt wird." It is not necessary to adopt Weismann's terms, "ids, idants," etc., in order to use his definition. If the developmental possibilities are only one half as great in the daughter nucleus as in the mother nucleus, there has been a reduction in Weismann's sense. If a nucleus contains four elements which happen to be two pairs of identical elements, the formula would be

$$\begin{array}{ccc} & n & \\ & | & \\ x & \begin{array}{c|c} a & a \\ \hline b & b \end{array} & y. \\ & | & \\ & m & \end{array}$$

Now, if the division takes place along the line $x\,y$, there is a reduction in Weismann's sense; but if the division be along the line $m\,n$, it is an equation division. Either division would reduce the chromatic *mass*, but only the first would reduce the number of *different* elements (ids) in the daughter as compared with the mother cell.

Since the rings, or Vierergruppen, have already been found in the oögenesis and spermatogenesis of numerous species in different groups, this arrangement of the chromatin just before the maturation divisions is certainly very general, if not practically universal. In order, therefore, to interpret properly these two divisions, and to come to any sound conclusions with regard to the reduction question, it is of fundamental importance carefully to study the formation of the Vierergruppen. Häcker ('93) and vom Rath ('93) have already called attention to the fact that the double longitudinal splitting of the chromatic thread, maintained by Boveri and Brauer, must bring about groups of four *identical elements.* The formula for a Vierergruppe would then be $\left\{ \begin{matrix} a & a \\ a & a \end{matrix} \right\}$. There could not in this case be any Weismannian reduction in either division, for there is only one *kind* of *id* in all the four elements of the group. If the Vierergruppen always arose as Brauer describes the process, — i. e. by two longitudinal splittings of the *chromatic granules,* which alone, he believes, possess an individuality, — then the four components of each group would be identical, and there could be no reduction division. Brauer therefore contends that a Weismannian reduction is impossible in karyokinetic division, and indeed never occurs. For Brauer the reduction question has consequently found its final solution: There is no reduction except merely one of mass. This would offer a very simple answer to the problem. But Henking ('90, '91, '92), Rückert ('92, '93), Häcker ('91, '93), and vom Rath ('91$^a$, '92, '93) have been able to see only *one* longitudinal splitting. I have seen no evidence of *any* such splitting of the chromatic thread in Caloptenus. Since coming to that conclusion, I have read in Born's paper on the egg of Triton ('94) that he finds a doubling in the number of the chromatic elements during the germinative-vesicle condition, but this doubling does not result from a longitudinal splitting. The chromatic thread divides transversely into twice as many segments as there were chromosomes in the Ureizelle. Born's statement that "eine Verdoppelung durch Quertheilung stattfindet" is in essential agreement with my results.

A remark by Wagner ('92) — to the effect that twice as many chromosomes arise during the resting stage immediately before the first maturation division as were in the cells of the preceding generation, but that this does not imply any such definite longitudinal splitting as Brauer and other authors maintain — may also be interpreted as in harmony with my conclusions.

Since the chromatin in the resting stage is very finely divided, — at least into finer particles than the "Chromatinkörner" to which Brauer ascribes the dignity of individuality, — it seems to me just as arbitrary to consider these homogeneous "Chromatinkörner" units, which by division must give rise to identical daughter grains, as to make the same supposition with regard to the chromosomes.

But further, even if we grant for a moment that the Vierergruppen do arise by two longitudinal divisions of the chromatic granules, what evidence have we that each Vierergruppe consists of four identical elements? Brauer maintains that both these splittings take place very early in the resting stage. The granules are extremely small. Each chromatic quarter of the group increases considerably in size. This growth takes place while they are separated (held together only by linin threads). There is still the probability that chromatic substance is formed in the nucleus during the process, and becomes associated with the substance of the Vierergruppen. In order to insure the identity of the elements of a Vierergruppe, two longitudinal divisions must take place after all growth of the chromatin has ceased, and we must at the same time assume that the chromatic elements are homogeneous, or, if they are not homogeneous, that there is an exact halving of the component particles of the elements of the Vierergruppe. But Brauer considers the four elements of a group identical because they all arise, by two divisions, from one.

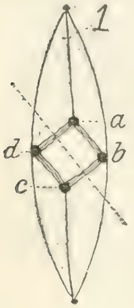
Again, if this whole process be only to secure a reduction of the *mass* of chromatin, the doubling of the chromatic elements, and the long, laborious process of mitosis would be unexplained and unjustified, as Weismann has pointed out; for a halving of the mass could be brought about by amitotic division. According to Weismann, the formula for Brauer's Vierergruppe would be (Häcker, '93) $\left\{\begin{matrix} a & a \\ a & a \end{matrix}\right\}$. We start with one element, $a$; this undergoes two longitudinal splittings, and then two separations by the two maturation divisions, and we then have just what we started with. The series formulated would be

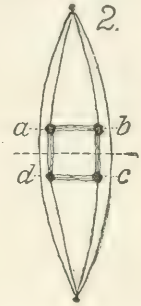
$$a \qquad \begin{matrix} a \\ a \end{matrix} \qquad \begin{matrix} a & a \\ a & a \end{matrix} \qquad \begin{array}{c|c} a & a \\ a & a \end{array} \qquad \begin{array}{c|c} a & a \\ \hline a & a \end{array}.$$

But Henking, Weismann, Häcker, Rückert, vom Rath, and others allow only one longitudinal splitting, and their formula for the Vierergruppen, as stated by Häcker ('93), and accepted by vom Rath ('93), is $\begin{matrix} a & a \\ b & b \end{matrix}$. This evidently permits only one reduction division in the Weismannian sense. Vom Rath and Weismann are therefore inconsistent when they hold to a longitudinal splitting in the spirem condition, and yet consider both maturation divisions as reductions. If the Vierergruppen have the formula $\left\{\begin{matrix} a & a \\ b & b \end{matrix}\right\}$, there are but two sorts of ids, $a$ and $b$, and it is simply impossible to get more than one reduction division. If from the nucleus $\begin{matrix} a & a \\ b & b \end{matrix}$ arises by division two nuclei, $\begin{matrix} a \\ b \end{matrix}$ and $\begin{matrix} a \\ b \end{matrix}$, this is by Weismann's own definition an equation division, and only when these two cells become by division the four ultimate products of maturation *a*, *b*, *a*, *b*, can we speak of a reduction.

Häcker at first considered both divisions as reductions ('92), but later ('93) he rightly came to the conclusion that the longitudinal splitting in the spirem stage was a preparation for one division, and that the final separation of the sister elements thus produced constitutes an equation division, — a "modified equation division," he calls it, because the splitting, which ordinarily occurs at the equator of the spindle is here precociously introduced in the spirem condition.

According to my interpretation of the Vierergruppen in Caloptenus, the formula would be $\left\{\begin{matrix} a & b \\ c & d \end{matrix}\right\}$. Both the divisions following the formation of a Vierergruppe would therefore be reductions, and it would be quite immaterial whether the first division gave rise to two cells *a b* and *c d*, or to the two cells *a c* and *b d*. In Caloptenus the rings may be placed upon the spindle equator in either of the two positions represented in Diagrams 1 and 2.

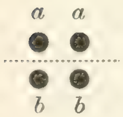




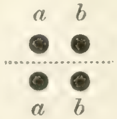
This offers, perhaps, an explanation and reconciliation of the contradictory views of Henking, Hertwig, Häcker, and others. As has been said, Henking holds that the first division is a reduction division, and the second an equation division, while most authors make the first an equation, and the second a reduction division. Henking ('91) did not, in his Pyrrhocoris paper, recognize the existence of Vierergruppen as a regular stage in maturation; but I feel justified by his Figure 20 in believing that they were really present in Pyrrhocoris, just as in Gryllotalpa, Caloptenus, etc. Now, supposing the proper formula for the Vierergruppen to be $\left\{\begin{matrix} a & a \\ b & b \end{matrix}\right\}$, why might it not happen in different nuclei, or in different chromatic groups of the same nucleus, that one group should divide thus, $\frac{a\ a}{b\ b}$, and another thus, $\begin{array}{c|c} a & a \\ b & b \end{array}$? Henking must assume that all the groups are arranged on the spindle so as to separate the non-identical idants by the *first division*. Häcker says: "In der *zweiten* Richtungstheilung erfolgt dann die definitive Trennung der nichtidentischen Idantenpaare."

The following diagrams may illustrate these positions: —

I.



II.



III.

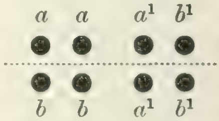


Diagram I. illustrates Henking's view of the first division interpreted according to the scheme of the Vierergruppen. All the groups would thus suffer reduction division.

Diagram II. serves to represent the view of Häcker, Weismann, vom Rath, and others. The first division is here seen to be an equation division. But none of these authors has offered any reliable criterion by which we may judge whether it is the "sister idants" or the "non-identical idants" that are separated by the first division. They have presented no satisfactory evidence that in the same nucleus all groups undergo either a reduction division or an equation division. How are we certain that one group does not undergo a reduction division at the same time that another in the same nucleus passes through an equation division? This possibility, as shown in Diagram III., is not excluded. Häcker ('92, Fig. 22, and '93, Fig. 116) believes he has seen two examples where the *non-identical* idants were still in connection with each other after separation of the sister pairs in the formation of the first polar globule, but the figures are rather unsatisfactory.

This discussion will, I hope, have made one thing clear: the absolute necessity of a knowledge of the *origin* of the Vierergruppen, in order to a proper interpretation of the reduction question. If Brauer's account of the origin of the Vierergruppen be correct, there can be no reduction. If Häcker and vom Rath have rightly described their origins, there is one, and only one, reduction. If my description of the ring formation be accurate, there may be two reductions. I am quite willing to grant that, as Brauer maintains, precocious preparations for both divisions are made in the prophases of the first spermatocyte division. But Brauer maintains an origin for the groups of four, which determines that each group shall consist of four identical elements, and thus does away with Weismannian reduction, while I contend that, owing to the manner of their origin, all four elements may be different or unlike one another, and therefore that both divisions may be reductions.

The fate of a Vierergruppe, according to the four views mentioned, may again be brought together in diagrammatic form for comparison.

Brauer: —

$$a \qquad \begin{matrix} a \\ a \end{matrix} \qquad \begin{matrix} a & a \\ a & a \end{matrix} \qquad \begin{array}{c|c} a & a \\ a & a \end{array} \qquad \begin{array}{c|c} a & a \\ \hline a & a \end{array}$$

Henking: —

$$\begin{matrix} a \\ b \end{matrix} \qquad \begin{matrix} a & a \\ b & b \end{matrix} \qquad \begin{matrix} a & a \\ \hline b & b \end{matrix} \qquad \begin{array}{c|c} a & a \\ \hline b & b \end{array}$$

Vom Rath, Häcker: —

$$\begin{array}{c} a \\ b \end{array} \qquad \begin{array}{cc} a & a \\ b & b \end{array} \qquad \begin{array}{c|c} a & a \\ b & b \end{array} \qquad \begin{array}{c|c} a & a \\ \hline b & b \end{array}$$

My view: —

$$\begin{array}{cc} a & b \\ c & d \end{array} \qquad \left\{ \begin{array}{c} \begin{array}{c|c} a & b \\ c & d \end{array} \\ \\ \text{or } \begin{array}{cc} a & b \\ \hline c & d \end{array} \end{array} \right\} \qquad \begin{array}{c|c} a & b \\ \hline c & d \end{array}$$

As to the question of reduction in the two maturation divisions, only four suppositions can be made: (1) the first division only is a reduction; (2) the second only is a reduction; (3) both are reductions; (4) neither is a reduction. As we have now seen, all these suppositions have been made by different authors. We may well say with vom Rath, that "eine allgemein befriedigende Lösung ist nur dann möglich wenn die Autoren sich zuerst über den Begriff 'Reduction' völlig geeinigt haben."

The assertion of Häcker and vom Rath ('93), that the resting stage which immediately precedes the first maturation division is sometimes omitted, has intimate connection with the question of reduction, and its meaning, it must be admitted, is not yet entirely explained. The accounts of Häcker and vom Rath are too meagre to allow a detailed comparison of the processes in cases where there is no "Keimbläschenstadium" with those in which it exists. Perhaps we can never settle definitely the question of reduction, but *material for its solution should be sought in a careful determination of the origin and meaning of the Vierergruppen.*

Cambridge, May 16, 1894.

## POSTSCRIPT.

In the Bulletin of the College of Agriculture of the Imperial University of Japan has recently appeared a paper by Kametaro Toyama ('94), "On the Spermatogenesis of the Silkworm." The author has arrived at conclusions which in part agree with my own, but in part are quite different.

Like myself, Toyama was unable to find any longitudinal splitting of the chromatic thread in the prophases of the first spermatocyte division. He gives the following account of the complicated series of movements of the chromatin during the prophases: "A nucleolus is generally seen in the network of linin and chromatin. . . . Most of the chromatin granules become collected to one side of the nucleus and form an irregular mass, . . . become again separate from each other and arrange themselves along the radiating linin fibres, and the skein stage is thus obtained. . . . The chromatin granules scattered in the nucleus become again collected in the centre of it, and present an irregular mass as before. . . . In a still later stage the chromatin granules again commence to separate from one another. . . . A little before the appearance of the centrosomes in sperm-mother-cells the chromatin granules . . . gradually collect here and there and assume ring-shaped structures."

Unfortunately the author presents no satisfactory evidence for this series of changes. He may have seen all the stages which are enumerated above, but he gives no proof that they succeed one another in the order he has stated. In the earliest prophases Toyama finds the chromatin in nearly the same condition in which I find it in Caloptenus, and just before the first maturation division he finds the chromatin arranged in quadrivalent rings. The progress toward the ring stage is, according to his account, twice interrupted by retrogressive processes. One cannot easily conceive the purpose of these complications, and the evidence for such an hypothesis could never be conclusive without direct observation of the process in the living condition. I know no reason why we might not arrange Toyama's Figures 23–43 in one continuous series. All stages represented in those figures are very young, and the numerous intermediate stages between them and Figure 44 are not shown. The concentrated condition of the chromatin seen in the author's Figure 30 seems to me due to bad preservation.

I disagree entirely with Toyama as to the processes in the maturation divisions. Toyama thinks that the Vierergruppen break up into their four elements, and that these arrange themselves around the equator of the spindle in a single row. He has figured spermatocytes with seven Vierergruppen (Figs. 44, 45), and he tells us that there are 28 separate chromosomes on the spindle of the first maturation division. We must seek his proof of this statement in his Figures 50–52. These seem to me to present seven quadrivalent rings, rather than 28 single chromosomes. In his Figure 50 Toyama has represented only 7 chromatic bodies on the spindle. Are we to suppose that there were 21 on the other side of the spindle? Our author has given no equatorial view of the spindle in which simple spherical chromosomes are arranged in one row. His Figures 50 and 51 represent what he has considered stages in the transverse division of the simple chromosomes. But I have seen in Caloptenus chromatic *rings* in such a position as to give exactly the same appearance. In Caloptenus there is no transverse division of the chromosomes in the maturation divisions. The ring does not break up into four simple chromosomes before the period of metakinesis. The separation of the ring into its four constituent elements takes place upon the equator of two successive maturation spindles. On the first spindle each ring is separated into two dumb-bell figures. On the second spindle each dumb-bell divides into its two simple chromosomes. Both of these divisions are effected by a breaking of the linin fibres between the chromosomes, not by division of the chromosomes themselves.

Toyama's description of the origin of the "Nebenkern" from the remains of the interzonal filaments of the last spermatocyte division is essentially the same as I have given for Caloptenus, but he has followed its fate in the spermatozoön farther than I was able to do. His "mitosoma" may be identical with the body which I find in the neck of the spermatozoön of Caloptenus.

January 19, 1895.

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# EXPLANATION OF PLATES.

Figures 1–104 (Plates I. and II.) are from *Cicada tibicen;* Figures 105–244 (Plates III.–V.) from *Caloptenus femur-rubrum.* All figures were drawn by means of an Abbé camera lucida. The tube was drawn, giving a length of 199 mm. Zeiss lenses were used in all cases. Figures 14 and 108 were magnified 90 diameters; Figures 7, 8, 12, 13, and 19–22, 870 diameters; Figures 227–229, 231, and 242, 1,080 diameters; Figures 62–77, 1,400 diameters; all other Figures, 680 diameters.

## PLATE I.

*Cicada tibicen.*

Fig. 1 *a–e*. Spermatids in various stages of metamorphosis.
Fig. 2. Spermatid with nucleus Nebenkörper and small red body.
Fig. 3. Spermatid, tail undeveloped.
Fig. 4. Spermatid immediately after second division of spermatocytes.
Figs. 5, 6. Spermatids.
Fig. 7. Spermatogonium with centrosomes near nucleus.
Fig. 8. Spermatogonium after amitotic nuclear division. Degeneration.
Figs. 9, 10. Spermatids.
Fig. 11. Spermatogonia.
Figs. 12, 13, 21, 22. Stages in development of giant spermatozoa.
Fig. 14. Longitudinal section of testicular follicle.
Figs. 15–18, 24–43. Stages in the metamorphosis of spermatids. See also Figs. 44, 45 (Plate II.).
Fig. 23. Part of compartment *c* of Figure 14. To the left of the connective tissue dissepiment are spermatogonia; to the right, below, are spermatocytes of the first order; above, spermatids.
Figs. 19, 20. Degenerating spermatogonia. Fig. 19 with two extranuclear bodies, centrosomes ?

WILCOX.—SPERMATOGENESIS

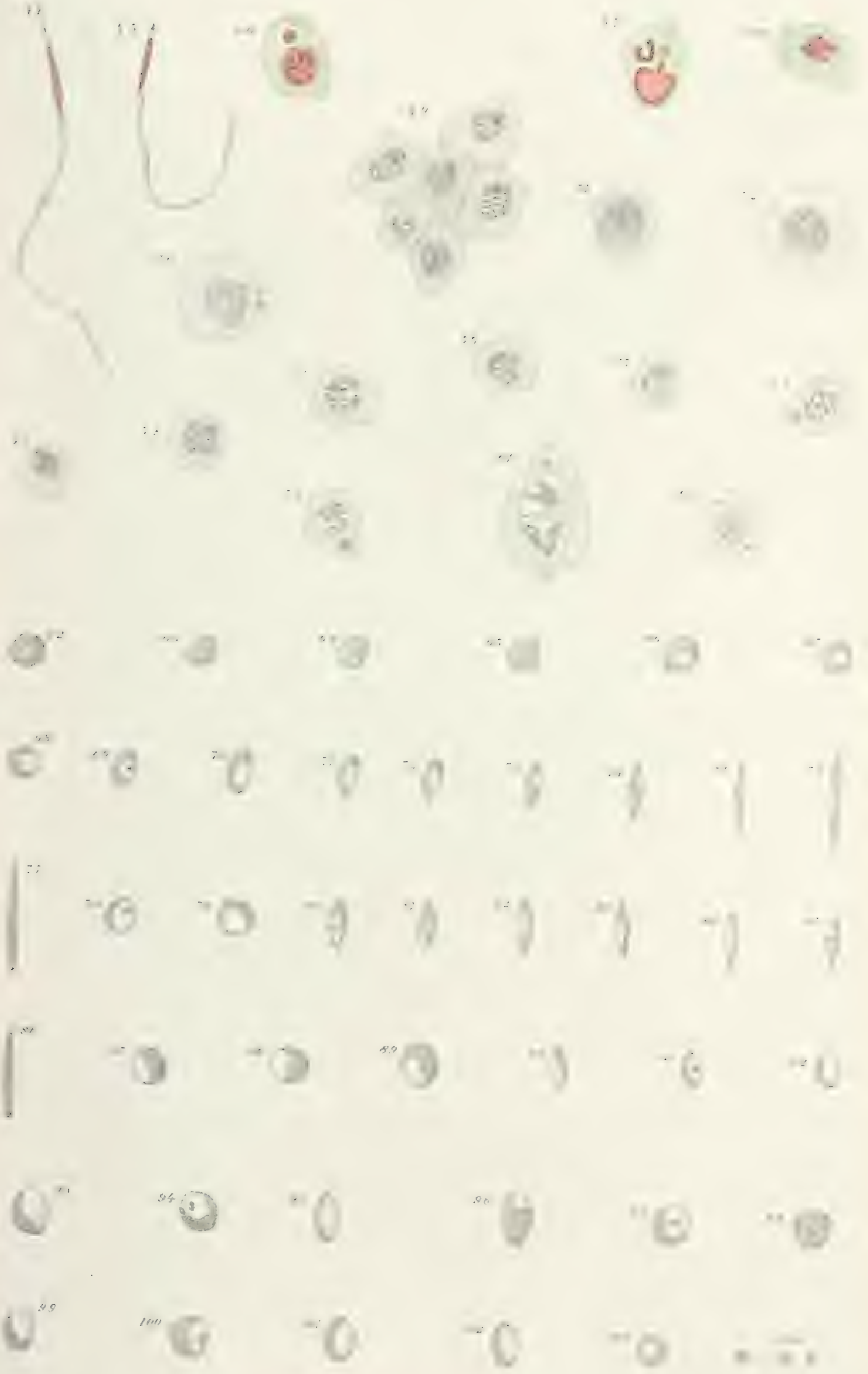
[illegible]

## PLATE II.

*Cicada tibicen.*

| | |
|---|---|
| Figs. 44, 45. | Advanced stages in the metamorphosis of spermatids. |
| Figs. 46–48. | Spermatogonia. |
| Figs. 49–61. | Spermatocytes, showing different positions of the body I suppose to be the nucleolus. |
| Figs. 62-77. | Metamorphosis of spermatids, × 1,400. |
| Figs. 78–103. | Metamorphosis of giant spermatids, × 680. |
| Fig. 104. | Normal spermatids from same microscopic field as Figures 78, 103, × 680. |

– SPERMATOGENESIS.



## PLATE III.

*Caloptenus femur-rubrum.*

Figs. 105–107. Spermatogonia.

Fig. 108. Longitudinal section of testicular follicle. *a*, spermatogonia; *b*, growth zone of spermatocytes; *c*, first division of spermatocytes; *d*, first stages of spermatids; *e*, later stages of spermatids; *f*, abortive spermatogonia.

Fig. 109. Cross-section of vas deferens containing spermatozoa.

Figs. 110, 111. Spermatocytes in the spirem stage.

Figs. 112, 113, 117, 118, 122, 123. Spermatocytes in the first division.

Fig. 114. Spermatocyte of the first order before dumb-bell stage of chromatin.

Figs. 115, 116. Spermatocytes of the first order in the dumb-bell stage of chromatin.

Figs. 119–121, 124. Spermatogonia in division.

Figs. 125, 126, 129. Spermatids just after division of the spermatocytes of the second order.

Fig. 127. Spermatocyte, first division.

Fig. 128. Spermatocyte, second division.

Fig. 130. Spermatocyte before first division.

Fig. 131. Spermatogonium, polar view of spindle.

Figs 132–138. Spermatogonia in division.

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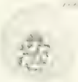
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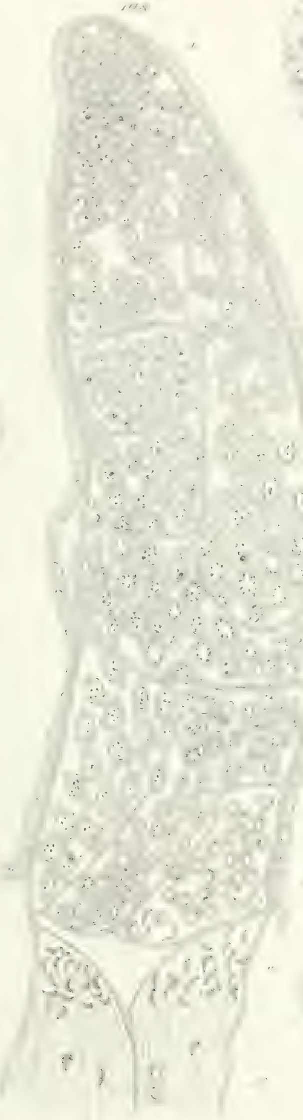
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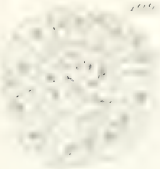
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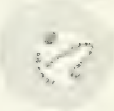
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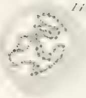
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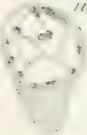
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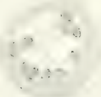
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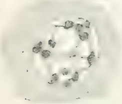
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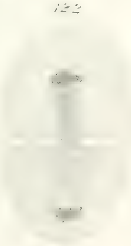
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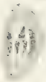
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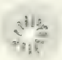
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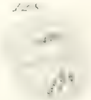
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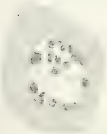
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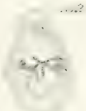
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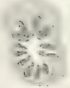
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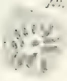
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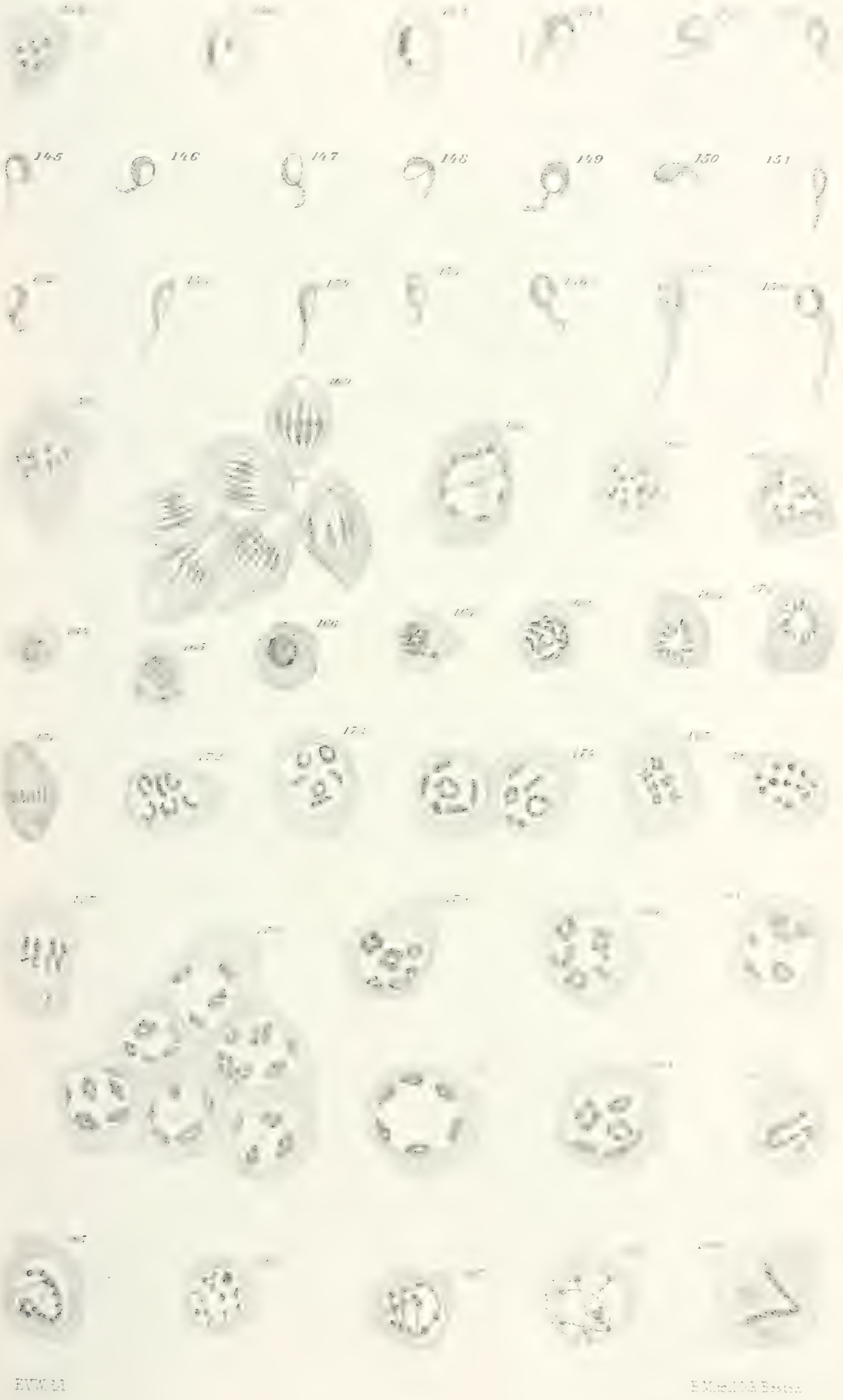
E.V.W. del.

B. Meisel lith. Boston

## PLATE IV.

*Caloptenus femur-rubrum.*

| | |
|---|---|
| Figs. 139–158. | Spermatid metamorphosis. |
| Figs. 159, 160. | Spermatocytes, first division. |
| Fig. 161. | Spermatocyte, preparatory to first division. |
| Figs. 162, 163. | Spermatocytes with chromatin in dumb-bell stage. |
| Figs. 164–171. | Spermatogonia. |
| Figs. 172–176. | Spermatocytes, stages in ring formation. |
| Fig. 177. | Spermatocyte, first division. One centrosome is cut away in another section. |
| Figs. 178–183. | Spermatocytes, ring stages. |
| Figs. 184–188. | Spermatocytes, spirem stages. |
| Fig. 189. | Spermatogonium, tripolar division. |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E.V.W. del.

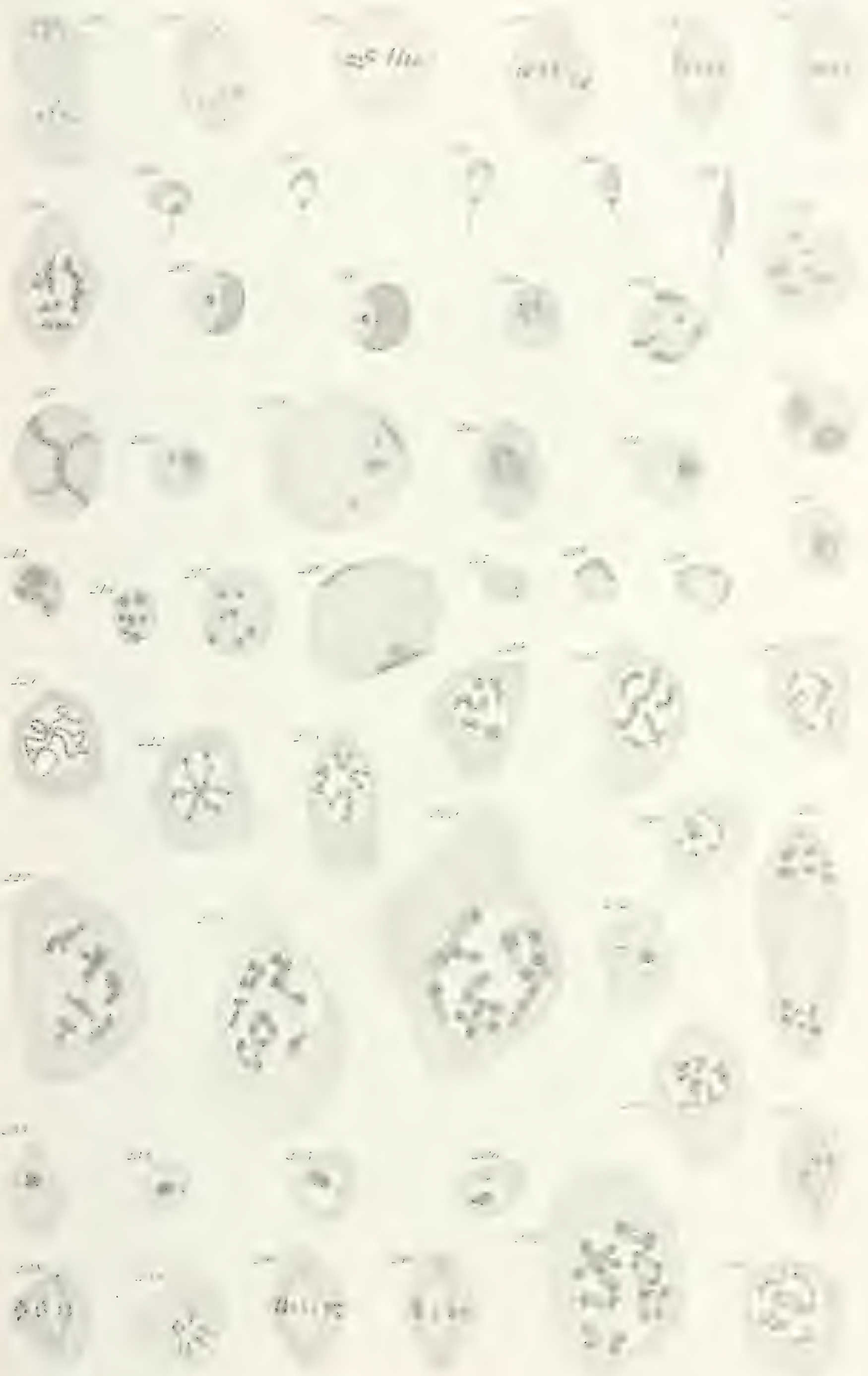
B. Meisel lith. Boston.

# PLATE V.

*Caloptenus femur-rubrum.*

| | |
|---|---|
| Figs. 190, 191. | Spermatocytes, second division. |
| Figs. 192–195. | Spermatocytes, first division. |
| Figs. 196–200. | Spermatid metamorphosis. |
| Fig. 201. | Spermatocyte just before ring condition. |
| Figs. 202–220. | Degenerating cells. |
| Figs. 221–229, 244. | Spermatocytes, preparatory to first division. |
| Figs. 230, 232–236. | Spermatids. |
| Fig. 231. | Spermatocyte, second division. |
| Figs. 237–241. | Spermatocytes, first division. |
| Figs. 242, 243. | Spermatocytes, ring formation. |

[illegible].—SPERMATOGENE



# No. 2. — *On the Early Development of Limax.*[1] By C. A. Kofoid.

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## I. INTRODUCTION.

The question of the origin and history of the mesoderm, and its relation to the body cavity in the Mollusca, is one of prime interest and importance. The employment of the mollusk as the type of the "Pseudocoels" by the Hertwigs ('81) in their "Coelomtheorie" was founded on the non-existence in mollusks of a true body cavity, the mesenchymatous nature of the musculature, and the origin of the nervous system, in part at least, from the mesoderm; in a word, on the nature of the middle germ layer in its origin and later history. Since the publication of this important work many additions have been made to our knowledge of the Mollusca. There is a notable agreement among later investigators, especially Schmidt ('90), Miss Henchman ('91), and Erlanger ('91), as to the *ectodermal* origin of the nervous system in this group. Studies in comparative anatomy, particularly of that primitive group, the Solenogastres, have led to the general acceptance of the view that the pericardium of the Mollusca is the homologue of the cœlom of the "Enterocoels" of the Hertwigs. This view is based upon the relationship of the pericardium to both the sexual and excretory systems, embryology however having lent little support to the view until the recent important work of R. von Erlanger ('91) upon Paludina, in which he demonstrates that the mesoderm originates by a pair of ventral out-pocketings, and that there is a close connection, though not *continuity*, of the paired fundaments of the pericardium with these out-pocketings. As yet his results are isolated, and the hope that a similar origin of the mesoderm might be found in other Mollusca is unfulfilled, at least so far as other investigators are concerned.

---

[1] Contributions from the Zoölogical Laboratory of the Museum of Comparative Zoölogy at Harvard College, under the direction of E. L. Mark, No. XLVIII.

The generally vague and often contradictory results obtained by various investigators of molluscan embryology concerning the origin of the mesoderm have made very apparent the need of careful and detailed work along the lines laid down by Rabl ('79), Blochmann ('81), Wilson ('92), Conklin ('92), and Heymons ('93). It is only in the light of such work as this that a classification of sweeping import, like that of the Hertwigs' "Coelomtheorie," can find its final justification, if it has one.

It was with a view of adding something to our knowledge of the details of this subject that the work in hand was undertaken. The pursuit of this has led me unavoidably into the study of the cleavage, and to a certain extent into the field of cell lineage.

Limax seemed for many reasons to be a desirable object for my investigation. The adults are readily procurable, and an abundant supply of eggs whose age is approximately known can be obtained from animals kept in confinement. The absence of a large amount of nutritive yolk leaves the eggs sufficiently translucent for examination *in toto*, and makes section-cutting feasible, though the smallness of the eggs renders their orientation in certain stages difficult.

My work was begun in the fall of 1892, at the suggestion of Dr. E. L. Mark, to whose kindly interest and guidance I owe very much. Agriolimax agrestis L. was the species chosen for the work, as the adults are abundant at that time of the year about piles of rubbish and stone heaps, — in fact, wherever decaying vegetable matter and moisture afford food and a suitable retreat. After the last of November, a supply of adults can generally be secured in greenhouses.

The eggs of other Limaces can also be collected in the same localities, and as those of Agriolimax agrestis are not readily distinguished from some of them, recourse was had to eggs of known parentage only.

## II. METHODS.

The most successful method of keeping the animals in captivity was found to be as follows. A tin box with proper ventilation is filled to the depth of one inch with clean sand, which forms a suitable substratum for the retention of moisture. On this is laid down a sheet of moss, to whose under surface the earth still adheres. The leaves of the common plantain furnish acceptable food, and, when this is no longer available, fresh cabbage leaves and apple parings can be used. The eggs, which seem more often to be laid at night, are found in clusters in the soil, or cunningly packed away in the moss itself. The rate of development is such at the ordinary temperature of the laboratory that the eggs collected in the morning will generally be found to have already reached the early stages of cleavage, while gastrulation progresses during the second day, and is completed early in the third. During the first week of captivity the slugs furnish eggs in great abundance; but after that time the number diminishes and the quality deteriorates so rapidly that it is imperative that a new colony be secured. Abnormalities in the living egg show themselves in the early stages by a loose assemblage of the cells, and the increasing opacity of the embryo.

Before hardening the embryo, it is necessary to free it from the envelopes and albumen which surround it. As the eggs of Agriolimax agrestis are much smaller than those of Limax maximus, it was not possible to employ the method described by Miss Henchman ('91) for shelling the eggs. But by inserting two fine cambric needles in one holder, so that the distance between the points is less than the diameter of the unshelled egg, it is possible to hold the egg between these two needles and pierce it by a third. A quick shear-like cut with the third needle against one of the other two tears open one side of the egg and allows the albumen and the ovum to escape from the envelopes. It is very desirable not to entangle the embryo in the viscous matter between the inner and outer envelope, for it is almost impossible to remove this when it is once attached to the embryo. The albumen interferes with section-cutting and obscures whole preparations, so that it is necessary to remove it entirely. This for a long time presented a most serious obstacle to my work. Washing off the albumen with water is a very slow and tedious process, and not always successful. Some of the eggs, after treatment with Merkel's or Flemming's fluid for a short time, were washed with hypochlorite of soda to rid them of the albumen. The difficulty of using this lies in the necessity of stopping the action of the hypochlorite before it attacks the ovum. It frees the eggs of the albumen, and does not interfere with staining, but the proportion of eggs destroyed in the process is very great. When the eggs are thrown into weak chromic acid (one fourth to one third per cent) or weak Merkel's fluid, the albumen is coagulated, and if the exposure is properly timed, the egg can sometimes be freed from its envelopes. It is difficult to get good series of sections of eggs hardened in their envelopes, or but partially freed from them. The process of dehydrating and embedding renders the albumen so hard and brittle that it breaks into bits when a microtome knife strikes it, and generally the whole section becomes shattered. This is especially true of eggs killed in any of the chromic fluids. The method of Schmidt ('90) for the later stages of Limax was employed with success for the early stages. The eggs are thrown into a saturated aqueous solution of corrosive sublimate, and as soon as they have become opaque they are washed in water, shelled, and freed from the coagulated albumen by a gentle stream of water from a pipette. There is less danger of distorting or destroying the egg in the process of shelling by this method than by any other I have employed; the disadvantages are that one is limited to this single killing reagent, and that it is often difficult to remove all the albumen.

The method which gives by far the best results is as follows. The living eggs are placed in normal salt solution (0.75 per cent), in which they are at once shelled, and then freed from the albumen by washing them in the salt solution, which is dropped upon them from a pipette. The operation is carried on in large glass dishes, resembling watch-glasses, but provided with flat polished bottoms, which are placed upon a black tile; this renders the eggs visible to the naked eye. The salt solution dissolves away the albumen, leaving the egg entirely free. It can then be transferred to any desired killing reagent by the use of a capillary glass tube. It is advisable to shorten the exposure in the salt solution as much as possible, for nuclear conditions are somewhat altered by its action. Eggs which have lain in it for ten minutes have their nuclear membranes much distended, and the chromatin, gathered into a homogeneous mass at the centre of the nucleus, surrounded by a clear region of nuclear sap. It is possible, however, by this method to obtain eggs whose nuclear conditions do not seem to be in the least changed.

For killing reagents the following were used: picro-sulphuric; picro-sulphuric with a few drops of one per cent osmic added to it (Erlanger, '91); Perenyi, followed by five per cent alum water; Whitman's Merkel; Fol's modification of Flemming's chrom-osmic-acetic, either alone or followed by Whitman's Merkel. By far the most satisfactory results were obtained by subjecting the eggs to the action of Fol's modification of Flemming's mixture for one minute and transferring them at once to Orth's picro-carminate of lithium. The eggs were allowed to remain in the stain twelve to twenty-four hours, and were then decolorized with acidulated alcohol until the cytoplasm retained but a slight tinge of red. Rapid decolorization with ninety per cent alcohol plus five per cent hydrochloric acid gave very good results. The eggs when properly decolorized have cell boundaries and nuclear membranes sharply marked, and the chromatic elements of the nucleus remain a deep red. Asters show plainly, but centrosomes are not stained. Eggs killed in Flemming's fluid and afterwards bleached by chlorine, or those killed in Merkel's fluid, are satisfactorily stained in Mayer's HCl-carmine. These also must be thoroughly decolorized. Eggs killed in corrosive sublimate were stained in alum-carmine or Czokor's cochineal, but the best results after this killing agent were obtained by the addition of a drop of Delafeld's hæmatoxylin to slightly acidulated water in which the eggs had been placed after hardening in alcohol (Conklin, '92). This is especially valuable for the demonstration of astrocœls in the early stages of cleavage. Satisfactory results were not obtained on whole preparations with Heidenhain's iron-hæmatoxylin or Henneguy's method with permanganate of potash and safranin. The first, however, gives very good results with sections.

The processes of killing, hardening, staining, and clearing were carried on in watch-glasses. Capillary glass tubing was found to be very convenient for transferring individual eggs when such transfer was necessary. Turpentine, xylol, or cedar oil was used as a clearing agent. Eggs can be kept without harm for a long time in turpentine evaporated down to a waxy consistency, or in xylol to which soft parafine has been added. If the xylol is allowed to evaporate, it leaves the eggs embedded in the soft parafine, which can be redissolved by fresh xylol without harm even to these very delicate objects.

The eggs were studied in the clearing agent under a cover-glass placed on glass rollers made of bits of capillary tubing. This allows the use of high-power objectives and the orientation of the embryo in any desired position for a camera drawing. When permanent preparations were desired, they were mounted in xylol-balsam or a solution of dammar in cedar oil. By the addition of a drop of xylol to the margin of the cover-glass, the mounting medium is sufficiently softened to allow the cover-glass to be moved upon the rollers, and the egg oriented as desired, even after the slide has stood for months.

The method of embedding and orienting preparatory to it described by Dr. Woodworth ('93) proved to be very valuable. The ordinary method of orienting in melted parafine on the warm stage with the aid of a lens was also employed. Sections were cut 6.67 $\mu$ in thickness, and reconstructions of many stages were made in wax on a scale of three hundred diameters. Transverse, sagittal, and frontal sections were cut; though it was not always possible to orient the embryo exactly, the reconstructions revealed the direction of the sections in cases where there was doubt. Sagittal sections are more readily interpreted than the others, for in them the cells of the different germ layers are shown in the same section in such relations as to be more easily recognized than in sections in other planes.

In the discussion of sections the following orientation is used. The end called anterior is the one toward which the growing invagination is directed. At the time of gastrulation it is the larger end of the embryo. The opposite end is the posterior, and is marked at the stage preceding gastrulation by a greater thickness than the anterior end, due to the presence of the mesoderm. In the early stages of gastrulation the broader and shallower end of the blastopore lies anterior. At the completion of gastrulation the contracted remnant of the blastopore occupies a terminal position at the posterior pole. The chief axis is the antero-posterior one. The ventral surface is marked in the blastula by a greater convexity than the dorsal, but during the period of gastrulation by the growing invagination. Sections are called sagittal that are parallel to the plane which coincides with both chief and dorso-ventral axes; frontal, those that are perpendicular to the dorso-ventral axis; transverse, those that are perpendicular to the chief axis.

## III. NOMENCLATURE OF SPIRAL CLEAVAGE.

The earliest full discussion of spiral cleavage occurs in Blochmann's admirable work upon Neritina ('81). Fol ('75 and '76) had described the early stages in the cleavage of the Pteropods and the Heteropods, and Rabl ('79) the cleavage of Planorbis; but neither had entered into a full discussion of the lineage of the cells or the spiral character of the cleavages with which he was dealing. In Neritina the cleavage is unequal, and at the formation of the first set of micromeres we have the appearance of a small protoplasmic mass budded off from a larger mass. This conception of the cell division — the derivation of a small part from a large part — dominated Blochmann's nomenclature both of cells and of spirals. Accordingly, we find him designating a large mass of protoplasm, both before and after the small mass is budded off from it, *by the same name.* So also, when he comes to compare the spiral with the motion of the hands of a clock, he regards the *small* cell as *moving away from the large* cell, and designates the spiral accordingly. Other investigators of spiral cleavage — Lang ('85), Conklin ('91 and '92), Wilson ('92), Heymons ('93), Lillie ('93) — have, like Blochmann, dealt with forms presenting a greater or a less inequality in cleavage, and have found it convenient to employ the system inaugurated by Blochmann for their nomenclature of cells and spirals. There has arisen in the usages of these various authors, however, considerable confusion in the detailed application of their nomenclatures to this basis of reference. Indeed, as I have pointed out in a previous paper (Kofoid, '94), an author is not always able to avoid inconsistencies. This state of affairs is confusing and extremely annoying to the student who wishes to make a comparative study of cell lineage. However much the introduction of a new system of nomenclature is to be deplored, it seems to be justified for the following reasons. Cell lineage deals primarily with the *descent and fate of cells*, and is most conveniently traced by following the history of their *nuclei;* it is only secondarily concerned with the amount of yolk or protoplasm in the cells. The founding of a system of nomenclature, therefore, upon the relative sizes of cells, ignores wholly this fundamental proposition, and substitutes a basis of varying and uncertain nature. Furthermore, this system has caused the introduction, perhaps not necessarily, of the custom of designating cells of different generations by identical names; thus $A$ may be a cell of any one of a half-dozen different generations. In this, too, the principle of descent is ignored.

Finally and principally, the basis hitherto employed affords *no solid ground whatever for comparisons*, for it gives no logical method to be employed in cases of *equal* cleavage; and its application must vary with the varying distribution of the large cells in different species of animals. Thus it comes about that "homologous" cells, i. e. those of identical descent, must according to this system be named differently in different animals. It may be that the system as applied by these authors does furnish a means, readily grasped by the eye and the mind, of following the lineage in the particular form studied; but so long as it fails to form a basis for comparison, it is open to serious objection. It was with a view of meeting this objection and suggesting a suitable basis of comparison that I proposed, in a paper ('94) to which I must refer the reader for a detailed description, an entirely new principle of nomenclature of both cells and spirals. This is a strictly genealogical system, giving to each cell in the line of descent a separate designation, one determined moreover by the constant spatial relations common to all eggs, and not by the inequality of the cleavage characteristic of individual species.

The system presupposes the division of the egg into four quadrants designated $a$, $b$, $c$, $d$, placed in the order in which the hands of a clock move. These quadrants are occupied by the four blastomeres, *the quartet*, of the third generation. When this quartet, or any other quartet of the later stages, divides, forming two quartets, each cell is designated as follows: (1) by a letter indicating the *quadrant*, as, e. g., $a$; (2) by a first exponent indicating the *generation*, $a^3$, $a^4$, etc.; (3) by a second exponent indicating the *position* of the quartet with reference to all other quartets of the same generation, potential or actual, the quartets being numbered from the vegetative toward the animal pole, as $a^{4.1}$, $a^{4.2}$, etc. Thus the cell $a^3$ divides, forming $a^{4.1}$ and $a^{4.2}$; in the second exponent the *odd* one being always given to the cells of the quartet which is nearer the vegetative pole, and the *even* to those of the quartet nearer the animal pole. I have previously described ('94) the simple and constant manner in which the designation of the daughter cells can in every case be derived from that of the mother cell.

It may be well to call attention here to the significance of this system of nomenclature. It designates cells as they might be named in the simplest possible mathematical and mechanical conditions of a cleaving egg, i. e. equal, regular cleavage pervading all the cells of a generation at the same time. In such a case we should have all the quartets of a generation actually present and numbered in the regular succession of their position from the vegetative to the animal pole. The possibility of referring all forms of spiral cleavage to such a simple type is obvious, and the advantage, if not indeed the necessity, of such a reference as a basis of comparison is equally apparent. The fact that in the application of this system the exponents have little or no significance, or are even misleading, as to the *actual* number of quartets present between a given quartet and the vegetative pole, is thus no obstacle, when once the real significance of the system is understood. In fact, it is rather an advantage that the regions of most rapid growth in the embryo are thus prominently designated. There are doubtless objections that will be encountered in the application of the system. After the ninth generation of cells the exponents become exceedingly cumbersome, but this is an objection which applies to all other systems as much as, or to even a greater extent than, to this; and it may perhaps in many cases be avoided in the later stages by the introduction, for teloblasts and their progeny, of subordinate dichotomous systems based on combinations of the numerals 1 and 2, as introduced by Chabry ('87), and later adopted by Wilson ('92) in his subordinate systems. It is also true that the system, as proposed, does not optically differentiate the macromeres and the primary, secondary, and tertiary micromeres where it is desirable to distinguish these groups or their immediate descendants. This however is readily accomplished by the use of differential type, or even by other letters of the alphabet than *a*, *b*, *c*, *d*, but used in the same order.

There seems to be no doubt that this system can be applied wherever it is possible to divide the cleaving egg into equivalent quadrants, and thus to distinguish quartets of cells. I have myself applied it to the spiral cleavage described for various forms (see review of the literature), and my friend, Mr. Castle, has applied it successfully to the bilateral cleavage of Ciona and to that of Clavelina as described by Van Beneden et Julin ('84).

To make this system available in all cases, it is only necessary to apply the second exponent in a constant manner with reference to some spatial relations; e. g. in the case of Tunicate cleavage, with reference to the sagittal and transverse planes, starting in all cases from the vegetative pole.

In conclusion, it hardly needs to be suggested that the generation basis of comparison is about the only one that can be employed between the various types of cleavage; and I would add that it promises to be useful in the discussion of precocious development.

## IV. GENERAL SKETCH OF THE DEVELOPMENT.

Limax has spiral cleavage of the typical form, the spirals alternating in successive cell generations, right spirals resulting in the even generations and left spirals in the odd. The mesoderm is derived from the left posterior quadrant, and, as in Nereis, Umbrella, Crepidula, and Unio, the first mesoblast cell is $d^{7.2}$. An ephemeral, recurrent cleavage cavity appears at the two-cell stage, and recurs as late as the completion of the period of gastrulation. This cavity is excretory in function, and is induced by the environment of the egg. The primary mesoblast divides bilaterally, ultimately sinks below the general level, and forms two bilaterally placed mesodermal bands extending anteriorly. Their formation precedes and accompanies gastrulation, no lumina appearing at any time within them. The blastopore is at first broad and shallow, but it gradually deepens at the anterior end, and disappears from the posterior margin anteriorly, forming an elliptical pit on the median ventral surface. By a rapid growth in the latero-anterior lips of this pit, accompanied by an accumulation of mesoderm in these regions and a general readjustment of the axes of the embryo, the opening leading into the archenteron assumes a position at the former posterior margin of the blastopore. This remnant of the blastopore comes to lie in the anal region; the mouth breaks through at a later period upon the ventral surface of the embryo.

## V. CLEAVAGE.

### Introductory.

The cleavage of the egg of Limax takes place with considerable rapidity. The eggs are generally laid, in captivity, during the night, and in the morning one finds stages from the one-cell to the sixteen- and occasionally the twenty-four-cell stage. By six o'clock in the evening these eggs have reached the stages of twenty-four to forty or more cells. Gastrulation begins during the second day, and is completed on the third day. There is, however, much variation even in a lot of eggs found in one mass, and evidently laid by one individual. These differences may possibly be due to differences in the time of fertilization. Temperature exercises a profound influence on the rate of cleavage. Eggs about to pass into the twenty-four-cell stage at 6 P. M. were placed over night in a temperature a few degrees above freezing, and were found to have just reached that stage at 8.30 the next morning, and, though restored to the temperature of the laboratory, they did not progress to the next cleavage until 2 P. M. There are a few " stages " in the cleavage that are well marked, i. e. periods of apparent inactivity in which the egg continues for some time. These are the the two-, four-, eight-, sixteen-, twenty-four-, forty-four-, and sixty-cell stages. The periods alternating with these are marked by mitotic conditions in all or a part of the cells of the egg.

The animal pole of the mature and undivided egg is marked by the presence of two polar globules. These generally differ in size, the more distant, i. e. the first, being the larger. In stained preparations the larger one often contains a distinct nucleus with nuclear membrane and chromatic granules (Plate III. Figs. 20, 21). In the case figured here the two globules are closely applied to the surface of the egg. In the majority of instances, however, they lie at some distance from the egg in the albumen, and in the living egg often seem to have no connection whatever with the vitelline surface. Thus it happens that the polar globules are removed with the albumen in by far the larger part of the eggs shelled. A phenomenon observed occasionally in the later stages of the living egg is the increase in size of one of the polar globules and its subsequent collapse (Plate I. Figs. 9–11). In one case the globule reached a diameter half that of the egg itself. This is apparently caused by the absorption of fluid from the albumen, and in the case noted was followed by a collapse and a return to the normal size and shape. The eggs of Agriolimax agrestis vary a great deal in size, the limits being from 80 $\mu$ to 160 $\mu$ in diameter. The average size is about 100–110 $\mu$.

## A. Orientation of the Embryo.

In my treatment of the subject the orientation employed by Wilson ('92), Conklin ('92) and Heymons ('93) is followed. The first cleavage plane is transverse, the second sagittal, in relation to the future embryo. The polar globules are dorsal, the macromeres are ventral. This does not, however, distinguish the anterior and posterior poles, and I know of no way in which they can with certainty be determined in Limax. The cells of the two ends are equal in size, generally, and when slight differences can be detected on careful measurement, it is impossible to follow these differences during the protean phases of cleavage that intervene between the two-cell stage and the appearance of the first mesoderm cell, marking the posterior pole. Inasmuch as the mesoderm cell ($d^{7.2}$) comes from the left posterior quadrant, and is itself quite a large cell, while its sister cell ($d^{7.1}$) does not seem to be much smaller than other members of its quartet, I have always placed the larger of the two touching quadrants of the basal quartet in the position *left posterior*, rather than right anterior. I have been compelled to orient arbitrarily in many cases, when no difference in size could be detected, choosing one of the two positions 180° apart. In choosing the larger cell I have not followed the type of Umbrella, where without doubt the mesoderm comes from the smaller of the two cells in contact at the ventral cross furrow.

## B. Discussion of Cleavage.

### SECOND GENERATION. FIRST CLEAVAGE PLANE. TWO CELLS.

**Plate I. Fig. 14.**

It should be noted that the phrase "generation of cells" is used in its strict genealogical meaning, and not in the sense in which Fol ('75, '76), Blochmann ('81), McMurrich ('86), and Heymons ('93) have used the phrases "generation of micromeres" and "generation of cells." The processes of maturation, fecundation, and the formation of the first cleavage furrow have been described in detail in Dr. Mark's classic work upon Limax campestris. His published work was not carried beyond this stage, though he had continued his researches far into the later stages of development. The appearance of Fol's work ('80), which dealt largely with the embryology of Limax, and the pressure of other duties, have interfered with the completion and publication of his studies. Dr. Mark has very kindly placed his numerous drawings and careful notes in my hands, and they have been of invaluable assistance to me in my work. I shall not attempt to add to his complete description of the formation of the first cleavage plane, but shall begin my work with the stage represented in Plate I. Fig. 14. This is a lateral view of an egg which has just completed the first division. Warneck ('50) has stated that in Limax and Lymnæus this plane is oblique to the axis of elongation, instead of transverse to it, and has distinctly said that this conclusion was not based upon a deceptive orientation of the egg. Fol ('75) has described a similar occurrence in Cymbulia. I have found no evidence that in the least confirms this statement of Warneck's. At the stage shown in Figure 14 the two nuclei lie close to the approximated surfaces of the blastomeres, at a level about midway between the animal and vegetative poles; they are still quite small, and have only a very delicate membrane. Each has an elongated oval outline, with the long axis extending toward the astrocœl of the cell in which it lies. Their position indicates that in the progress of the cleavage furrow toward the vegetative pole the nuclei (daughter segments) were in some way carried downward toward that pole. Mark ('81) has described such a procedure in the eggs of Limax campestris. There are a number of deeply staining granulations in the peripheral part of the cell adjacent to the nuclei, which probably constitute the remnant of the cell plate; there is thus every indication of recent cell division.

The astrocœls appear as clear areas, almost as large as the nuclei, containing a few scattered deeply staining granules. These clear areas have no limiting membrane; they are, however, devoid of the granular structure of the surrounding protoplasm, and are the centres about which the radiations constituting the asters are arranged.

The position of the astrocœls with reference to the nuclei is worthy of note. They are removed some distance from the nuclei toward the animal pole of the cells in which they lie. A comparison of this figure with that of a later stage shown in Figure 5 indicates that the astrocœls are migrating toward a region where later the nuclei are found. It must seem therefore from the conditions in Figure 14 that the nuclei are preceded in this migration by the astrocœls. This recalls the shifting of male and female pronuclei attributed to the astrocœls by Conklin ('91) in Crepidula.

In the living egg of this stage, when the cells have reached a perfectly spherical shape, each blastomere seems to be entirely independent of the other, and not the least trace of any contact or connecting protoplasm can be detected between them. Each has a definite, unbroken contour, and in most cases there is an appreciable space between them, which shows no differentiation from the surrounding albumen. In the egg shown in Figure 14 the separation is not so great as it apparently is in the living egg. It is an interesting phenomenon, and raises the question as to the existence of any actual protoplasmic connection between the blastomeres in the stage following constriction. It is impossible to answer the question satisfactorily from observation of the living egg, for there is the possibility of the existence of a thin sheet of protoplasm which, on account of its transparency, thinness, and optical resemblance to the surrounding albumen, cannot be detected. The egg shown in Figure 14 was shelled by the process described in the preceding pages, and washed free from the albumen by normal salt solution, transferred in capillary tubes a number of times in the process of preparation, and, after mounting in balsam, was rolled over in various directions repeatedly *without a separation of the two blastomeres.* The two cells have each of them a definite and sharp outline at all planes of focusing, and even under high powers of the microscope no deeply stained granular bridge of protoplasm can be detected between them. It is only by very careful focusing that the rather vague, transparent, unstained connection between the cells can be seen. So far, then, as this preparation goes, it shows that there is a physical band of connection between the two blastomeres in this stage of greatest separation. The nature of this connection is problematical. It may be the Schleimschicht of Warneck ('50), or it may be a continuation of the "differentiated superficial portion of the yolk" noted by Mark ('81), there being no evidence of a well differentiated vitelline membrane. If the latter, then there is physical continuity in the living substance of the two blastomeres, and the appearance in the living egg is deceptive. Experimentation might possibly settle this interesting question.

The two cells now lose their individual spherical contours, owing to their apposition and the mutual flattening of the two faces in contact. Thus the nearly spherical outline of the whole egg is re-established. See Figures 1–6, which form a series showing successive conditions of a single egg, and render a detailed description of the process unnecessary.

The alternation of the rounded and flattened condition of cells during and subsequent to mitosis has been very generally observed in the stages of cleavage, but the explanation of the causes which underlie this phenomenon seems as remote as ever. Whitman ('78), in his discussion of the cleavage of Clepsine, concludes: "The cause of the separation and of the subsequent approach is undoubtedly the nucleus. . . . The proof that this is an electrical phenomenon is at present wanting, but the facts seem to point in this direction very strongly." Our increased knowledge of the part that the cytoplasm plays in the process of cell division, especially the directive rôle of the centrosomes, has suggested another influence to which we may turn for a solution, though the nature and exact operation of that influence is by no means definitely settled.

This first cleavage plane divides the egg into equal or approximately equal cells. In some cases, by careful measurement, a slight difference in size could be detected; in one case, for example, one of the cells measured 19 × 26 units of the ocular micrometer, and the other 20 × 27, when viewed from the animal pole. The theoretical consideration of the orientation of the early stages will be taken up later; suffice it for the present to say that the orientation adopted by Wilson ('92), and later by Conklin ('92) and Heymons ('93), will be employed in the present paper. The first cleavage plane, then, cuts the egg into an anterior half, *A B*, and a posterior half, *C D*, i. e. it is perpendicular to the antero-posterior axis of the egg.

The discussion of the cleavage cavity will also be deferred till a later part of the paper is reached.

### Third Generation. Second Cleavage Furrow. Four Cells.

**Plate I. Figs. 6–8; Plate II. Fig. 15–18.**

The second furrow is formed, at the ordinary temperature of the laboratory, about two hours after the appearance of the first. Like the first, it is preceded by an elongation of both cells in a direction at right angles to the plane of the division. Figure 15 (Plate II.) presents a view from the animal pole of a stage preparatory to this cleavage. The egg here represented is an exceptionally large one, being about 160 $\mu$ in its longest diameter. Each cell contains a spindle lying in its long diameter and nearer the animal pole. If the egg be viewed exactly from the animal pole, it is found that two of the asters — the rays of which are made more prominent in the figure than those of the remaining two — lie at a higher level than their mates. The same fact is brought out in a lateral view of this stage (Plate I. Fig. 7). Of the four asters the two having the same level lie in diagonally opposite quadrants of the egg. If we orient the egg so that the first plane of cleavage is transverse, no matter which pair of cells is placed anteriorly, and name the four asters *A*, *B*, *C*, *D*, in the accepted order, beginning at the left anterior quadrant, we shall have the asters *A* and *C* at the higher level, *B* and *D* at the lower. The slight difference in size between the two cells of this egg (Plate II. Fig. 15) has been previously noted. There is also a very slight difference in the stage of mitosis exhibited by the two cells, the larger being slightly more advanced than the smaller. A difference in the time of cleavage of the two cells of this stage has come under my observation in Limax a number of times. It is, however, not prevalent, and it is impossible to correlate it with any difference in the size of the two blastomeres. In Nereis, Umbrella, Cyclas, Unio, and many other forms, there is a well marked difference in size and a correlated difference in the time of division, the *smaller* cell being generally the first to divide.

Figure 8 (Plate I.) represents the second furrow just before its completion. The difference in level noted in the asters here finds its counterpart in the position of the partially formed blastomeres, the order of arrangement being the same as in Figure 15 (Plate II.). The planes of division are perpendicular to the axes of the spindle. They are therefore not continuous, but both are oblique to the vertical axis and in opposite directions. The posterior plane (separating *C* and *D*) passes from above toward the vegetative pole and the right, the anterior (separating *A* and *B*) from above toward the vegetative pole and the left. Inasmuch as the two derivatives do not lie at the same level, we may test the existence of the spiral; viewing the egg from the animal pole, and going from the lower derivative to the upper, we pass in a direction opposite to that in which the hands of a clock move; this oblique position of cognate cells may be referred to as a left spiral. It should be noted that this position of the cells is predetermined by the inclination of the spindles, which exists before there is any constriction of the cytoplasm. As in the case of the first cleavage plane, the constriction progresses most rapidly from the animal pole. Toward the close of the process of constriction the daughter cells are united by only a bridge of protoplasm, which is nearer the vegetative pole. Figure 16 (Plate II.), from a preparation of a slightly older stage, shows a similar bridge of protoplasm, but it is much nearer the animal pole.

The period of constriction is followed by a stage similar to that described for the two blastomeres, in which each of the four blastomeres assumes a spherical contour and stands out sharply and distinctly from its neighbors. This phase soon passes, and within half an hour the egg has assumed the condition of Figure 9 (Plate I.). This is the typical four-cell stage of the spiral type of cleavage, and therefore merits further description. (See diagram of this stage on page 52, Figure A.) The four cells, *A*, *B*, *C*, *D*, occupy the left anterior, right anterior, right posterior, and left posterior quadrants respectively. Each cell presents to the exterior a rounded, convex surface, and upon its inner side has three facets of contact, — the first and third with the cells of the adjacent quadrants, the second with the cell of the diagonally opposite quadrant. This last facet is triangular in shape, with its base at one pole and apex near the centre of the egg. The vertical axis of the egg lies in the planes of these central triangular facets. The bases of the central facets coincide with the well known cross furrows of the animal and vegetative poles of the egg (compare Plate II. Fig. 17). The cross furrow of the animal pole lies between the cells *A* and *C*, and extends from *D* to *B*, that of the vegetative pole lies between *B* and *D*, and extends from *A* to *C*. Thus by this mutual adaptation of the cells to one another, the spheroidal form of the egg as a whole is, in a degree, again restored, and here, as in the two-cell stage, persists during the period of "nuclear quiescence." I have referred to the condition in Limax as "typical." I mean that the conditions are simple, and that the modifying influence due to the presence of a large amount of yolk, and its equal or unequal distribution among the four blastomeres, is absent.

A comparison of the conditions presented here (Plate I. Fig. 9, Plate II. Fig. 17, and Fig. A, p. 52) with the same stage in other animals shows how profound the modifications are. In Limax the dorsal and ventral cross furrows are approximately equal in length, and as seen from the animal pole lie nearly at right angles to each other. In Nereis (Wilson '92) the dorsal furrow is largely obliterated, the four blastomeres almost meeting in a point at the animal pole, while the ventral cross furrow is correspondingly longer. In Umbrella (Heymons '93) the dorsal and ventral furrows of this stage are parallel, i. e. are formed between the same cells *B* and *D*, the cells *A* and *C* being considerably separated. This is undoubtedly due to the presence of a large amount of yolk in the four blastomeres. Likewise in Planorbis (Rabl '79) and Neritina (Blochmann '81) we find the dorsal and ventral furrows of this stage similar to those of Umbrella, rather than Limax. These cross furrows are an invaluable aid in the determination of the axes of the later stages; the question of their relations and constancy will be discussed later.

### FOURTH GENERATION. THIRD CLEAVAGE. EIGHT CELLS.

**Plate I. Figs. 8-13; Plate II. Figs. 17-19; Plate III. Figs. 20, 21.**

About two hours and a half intervene between the beginning of the four-cell stage and that of the eight-cell stage. The third cleavage is accomplished by the division of the quartet of the third generation, *A*, *B*, *C*, *D*, into two superposed quartets (cf. Figure B, p. 52), $A^{4.1} - D^{4.1}$, and $a^{4.2} - d^{4.2}$. The series of stages shown in Figures 8–13 (Plate I.) represents the egg during this process. Figures 17 and 18 (Plate II.) give apical and lateral views respectively of an egg with the spindles of this generation. It will be noticed (Fig. 17) that the spindles in no case stand vertically, but that they are inclined toward the *right* (right and left being used as resident in the egg; see my earlier paper, '94, p. 180). The division of the chromatin elements in the spindles has just begun, and there is no trace of a constriction of the cytoplasm. A comparison of Figures 17 and 19 shows that the degree of obliquity of the spindles has increased during the interval between the two stages. Figure 19 represents a stage in which the constriction of the upper from the lower quartet, i. e. of the micromeres from the macromeres, has just been completed. The obliquity increases during the division, so that at its close the cells of the upper quartet lie in the furrows between the cells of the lower quartet. Thus it will be seen that this apparent shifting of the upper quartet upon the lower, known as the "spiral," takes place in large measure during the division of the cells. It will also be noted that the plane of division is at right angles to the axis of the spindle.

If we view the egg from the animal pole and pass from the lower derivative of a pair to the upper, we move in the direction of the hands of a clock, and therefore the division of this, the fourth generation, takes place in a *right* spiral, whereas that of the third presented the character of a *left* spiral. Applying the system of nomenclature which I have adopted to the derivatives of the third generation, we find that cells of the lower quartet will be designated by the exponent 4.1, and the upper by 4.2. It will be convenient in the further discussion of quartets to refer to them simply by their exponents, without reference to the individual cells of which they are composed. It will be seen from Figures 17 and 19 (Plate II.) that the dorsal and ventral cross furrows at the close of this stage do not lie at right angles to each other, as they did at the end of the four-cell stage, but that they cross each other at an angle as much less than 90° as is represented by the shifting of the cells to produce the spiral, i. e. they now cross at about 45°, as seen in the accompanying diagrams (Figures A and B).

FIGURE A.

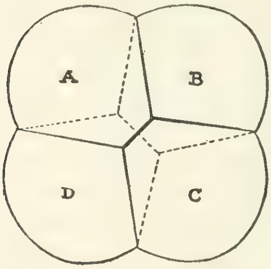

FIGURE B.

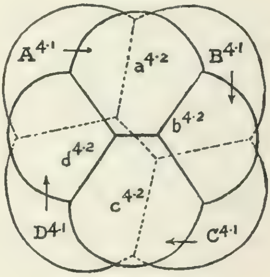

Figure A is a diagrammatic representation of the four-cell stage of Limax as seen from the animal pole, showing dorsal and ventral cross furrows. Figure B is the same of the eight-cell stage.

This condition is not quite realized in Figure 21 (Plate III.), owing to the near proximity of the succeeding division, which restores the cross furrows approximately to the conditions of the four-cell stage. Thus, in the typical eight-cell stage of Limax the cross furrows correspond to those of the same stage of Nereis (Wilson '92, Plate XIV. Fig. 11). In Umbrella likewise (Heymons '93, Taf. XIV. Fig. 4) the dorsal and ventral furrows are oblique to each other, crossing at about 45°, but differing in this important respect from the furrows of Limax and Nereis, that they are in this case formed by the juxtaposition of the cells of quadrants *B* and *D* at *both poles*, whereas in Limax and Nereis the ventral furrow only is formed by cells of these quadrants, the dorsal furrow being formed by $a^{4.2}$ and $c^{4.2}$, as is shown in Figure B. The furrows in Neritina (Blochmann '81) are similar to those of Umbrella. The conditions in the eight-cell stage of Planorbis (Rabl '79) are complicated by the fact that this pulmonate probably has reversed cleavage (cf. Rabl '79, Taf. XXXII. Figs. 7, 9), and that therefore the mesoderm arises by a right spiral instead of a left one, as in the case of the unreversed or normal type of cleavage. Orienting the Planorbis egg for the purpose of comparison after the method employed by Wilson ('92) for Nereis, we have the first mesoderm cell arising from quadrant *C* instead of *D*; and in the four-cell and later stages the ventral cross furrow lies between *A* and *C* instead of between *B* and *D* (cf. Rabl '79, Taf. XXXII. Figs. 7, 8 B, 11 B). The differences between Limax and Planorbis will be best shown by a comparison of Figures A and B with the corresponding stages of Planorbis given in the diagrams below.

FIGURE C.

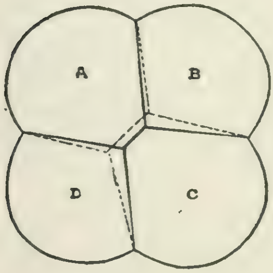

FIGURE D.

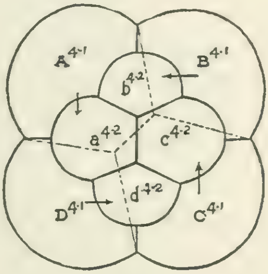

Figure C is a diagrammatic representation of the four-cell stage of Planorbis, showing dorsal and ventral cross furrows parallel. Combined from Rabl's ('79) Taf. XXXII. Figs. 7–12. Figure D, the same of the eight-cell stage.

It will be seen that in Planorbis, as in Umbrella and Neritina, — all of them forms with considerable yolk, — the dorsal and ventral furrows are both formed by the contact of cells of the *same quadrants.* On the other hand, in Nereis and Limax the furrows of the two poles are formed by the contact of cells of *different* quadrants. In Nereis, however, the dorsal furrow is comparatively shorter than in Limax, and in Umbrella it is of still less extent.

I have observed no difference in the time of cleavage of the different quadrants. The nuclear conditions in Figure 19 (Plate II.) indicate that the division is very slightly more advanced in the posterior half of the egg, but there seems to be no acceleration of the division in the mesoderm-producing quadrant *D* over the quadrant *C* in this egg.

The division, as has been before stated, is in individual planes oblique to each other, and not in a common equatorial plane such as occurs in radial division. In Limax the cells of the two quartets 4.1 and 4.2 are of unequal size, the inequality being almost as great as in Nereis; this will be seen on a comparison of my Figure 19 with Wilson's ('92) Plate XIII. Fig. 10. We may therefore distinguish the components of the larger quartet as macromeres, and the smaller as micromeres of the first set. This difference in size, so marked at this period, persists in Nereis to a very late stage of development, but in Limax it is practically obliterated at the division leading to the next generation. Hence it is that a system of nomenclature based on these distinctions loses its significance when applied to the approximately equal cleavage of Limax.

## Fifth Generation. Sixteen Cells.

With the formation of the two quartets of the fourth generation it has become no longer possible to designate a single cleavage furrow as producing the next generation. I shall therefore discuss the cleavage, from this time on, from the standpoint of the successive cleavage of quartets.

### *Division of Quartet* 4.1, *forming* 5.1 *and* 5.2.

**Plate III. Figs. 20, 21.**

The basal and larger quartet of the eight-cell stage is seen in a mitotic condition in Plate III. Figs. 20 and 21. Here, as in the previous division, the spindles are not vertical, but much inclined; this time, however, the upper asters of each spindle lie to the *left*,[1] and not to the right, of the lower ones (Fig. 20). The division of the chromatin elements has already taken place in the spindles of this quartet (best seen in Fig. 21), and the conditions of the completed mitosis can readily be inferred from the figures. If we view the egg from the animal pole, and pass from the lower derivative to the upper, we move in a direction opposite to that of the hands of a clock, i. e. this division takes place in a left spiral. The division of this quartet (4.1) is almost equal (Plate III. Fig. 22), the basal derivatives (5.1) being but slightly larger than the upper ones (5.2). In this respect Limax differs from all the yolk-laden forms, — Neritina, Planorbis, Umbrella, and Nereis, — where the cells of the basal quartet (5.1) retain their preponderance, and may still be designated as macromeres after this division.

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[1] Cf. Kofoid '94, p. 180, for explanation of the use of right and left.

The cell $d^{5.2}$ (somatoblast of Wilson) is not appreciably larger than the other members of the quartet to which it belongs.

### *Division of Quartet* 4.2, *forming* 5.3 *and* 5.4.

**Plate III. Figs. 20–23; Plate IV. Figs. 28, 29.**

The same stages which show spindles in the lower quartet also exhibit them in the upper and smaller quartet. The mitosis is not however so far advanced as in the lower quartet. The nuclear membrane can still (Figs. 20, 21) be traced, though the asters are present, and the axis of the spindle can therefore be determined. This, as in the lower quartet, is inclined; however, it is more nearly parallel to the equator than to the vertical axis. The inclination is in the *same general direction* as that of the spindles of the lower quartet, and the conditions of the completed division can be inferred as readily from the figures. Viewing the egg from the animal pole and passing from the lower derivative or aster to the upper, we move in a direction opposite to that of the hands of a clock, and this spiral, like that of the other quartet of this generation, is therefore a *left* one. This division, like that of the basal quartet, results in cells of almost equal size (Plate IV. Figs. 28, 29), the upper derivatives in this case (5.4) being, however, slightly larger than the lower (5.3).

The conditions in Figures 20, 21, show that the sixteen-cell stage will in this case follow immediately upon the eight-cell, without the intervention of a well marked twelve-cell stage. There is, however, so much variation in the rate of cleavage in Limax, that it might be expected that a twelve-cell stage would occasionally make its appearance. We have but to increase the difference between the mitotic conditions of the cells of the two quartets of Figures 20 and 21 to produce such a stage. Warneck ('50) figures in Tafel V. Fig. 46, a twelve-cell stage of Limax agrestis, and one egg in this stage has come under my own observation. This stage occurs regularly in forms with abundant yolk, as Planorbis, Umbrella, etc., but Nereis, like Limax, passes directly from the eight- to the sixteen-cell stage. The completed sixteen-cell stage is shown in Figure 22, Plate III., in which the genetic relations of the cells are still indicated by the approximated nuclei.

With the completion of the sixteen-cell stage and the fifth generation, the dorsal and ventral cross furrows are restored to the conditions of the four-cell stage, i. e. they cross each other at approximately right angles. A similar restoration to the conditions of the four-cell stage occurs in Nereis, also in Umbrella at the twelve-cell stage, and probably in Neritina.

In Planorbis, however, according to Rabl's ('79) interpretation, the cross furrow of the animal pole is not restored to the position of the four-cell stage, but is turned 90° from it (see his Taf. XXXII. Figs. 10 A, 11 A). To accomplish this it is necessary for each of the cells of the apical quartet (5.4) to be shifted 90° to the left, and thus completely out of their own quadrants over upon the adjoining quadrants. It seems very probable that Rabl is in error in this matter, and that in Planorbis, as in the other forms, the division of this generation results in the restoration of the cross furrows to the conditions of the four-cell stage.

An examination of the sixteen-cell stage (*cf.* Figs. 21, 22) shows that the cells of the apical quartet (5.4) lie in the same meridian as those of the same quadrant in the basal quartet, i. e. $a^{5.4}$ lies directly over $a^{5.1}$, $b^{5.4}$ over $b^{5.1}$, etc.; $a^{5.2}$, $b^{5.2}$, etc. lie to the left of the meridian of the quadrant to which they belong, and $a^{5.3}$, $b^{5.3}$, etc. to the right. Thus of the four granddaughter cells of the original blastomere occupying the quadrant, two only occupy the meridian corresponding to the middle of the quadrant, the other two being placed laterally to it, one upon either side. Similar conditions obtain in the corresponding stage of Nereis. In Neritina, Planorbis, and Umbrella, the fact that the twelve-cell stage is succeeded by the twenty-four-cell stage obscures somewhat the typical arrangement, though it can still be traced. It will readily be seen that, when the disturbing elements of unequal and non-synchronous division are removed, this arrangement of the four granddaughter cells will hold good for the descendants of *any* blastomere in spiral cleavage, and that normal and reversed cleavage will differ only in the transposition of the lateral granddaughter cells; e. g. in the case under discussion $a^{5.2}$ and $a^{5.3}$ would be in a case of reversed cleavage transposed. Owing, perhaps, to the unequal distribution of the yolk, this typical arrangement is not found in the sixteen-cell stage of Chiton as figured by Kowalevsky ('83) and Metcalf ('93), though it can be traced in the later stages. Metcalf says of this phenomenon, "*Each* cell then lies in the same meridian as its grandparent, — a fact shown more clearly in the cleavage of such eggs as those of Nereis and Crepidula." It is at once evident that this is but a partial and misleading statement of the case, since it ignores the fact that there are *four granddaughter* cells of every blastomere. It has its explanation in the confusing custom adopted in previous systems of nomenclature of regarding the larger of two daughter cells as the mother, the smaller as the daughter. In reality both are daughter cells, and the mother cell has passed out of existence with their origin, a fact which a logical system of nomenclature of *cell lineage* must always recognize.

### SIXTH GENERATION. THIRTY-TWO CELLS.

Following the formation of the sixteen cells of the previous generation there comes the usual rounded condition in which each blastomere asserts its individuality and diverges from its nearest of kin. This in turn is followed by the flattened condition, in which the spherical contour of the egg as a whole is restored. It is during this period that the spindles which begin the formation of the sixth generation first appear. As in the previous generation there was a lack of synchronism in the cleavage of the two quartets 4.1 and 4.2, as shown in the nuclear conditions of Figures 20 and 21 (Plate III.), so here there is a similar separation of the divisions of this generation into two mitotic periods, the first appearing in the largest cells of the embryo, viz. the two quartets at the vegetative pole, and resulting in the twenty-four-cell stage; the second involving the animal hemisphere, and resulting in the thirty-two-cell stage, thus realizing in this stage Warneck's ('50) conclusion that cleavage progresses according to the age of the cleavage spheres. The first phase is separated from the second by a period in which all the nuclei are in a resting condition. This period lasts some hours, and hence it is that cleavage stages killed at random contain a large proportion of eggs in the twenty-four-cell stage.

### *Division of Quartet* 5.1, *forming* 6.1 *and* 6.2.

**Plate III. Figs. 23-25; Plate IV. Figs. 27-32; Plate V. Figs. 33-36.**

Figure 23 (Plate III.) shows a lateral view of an egg at the completion of the first mitotic phase. The quartet 5.1 has divided, forming 6.1 and 6.2. Applying the test as in previous generations, it is readily seen that this is a right spiral. The remnants of the nuclear spindle and the asters leave no question as to the relationship of the cells in this egg. The upper derivative lies to the right of the lower one in every case. Reference to the quartets 6.1 and 6.2 in Figures 27–29, 31–34, 36, of four other eggs, shows the constancy of the direction of this spiral. The division in this quartet is about equal, and is synchronous in the four quadrants.

### *Division of Quartet* 5.2, *forming* 6.3 *and* 6.4.

**Same Figures as for 5.1.**

Figure 23 shows the quartet at the close of the division which has resulted in the formation of the quartets 6.3 and 6.4. The nuclear conditions in like manner show that this division has also taken place in a right spiral. The remnants of the spindles are parallel to those of the quartet 5.1, and the upper derivative lies to the right of the lower one. These divisions are also approximately equal and synchronous. The arrangement of the cells of the vegetative pole is very regular. The ventral cross furrow remains approximately at right angles to the dorsal furrow. The two cells $b^{6.1}$ and $d^{6.1}$ meet in this ventral furrow, and are hexagonal in outline, while the other two members of the quartet $a^{6.1}$ and $c^{6.1}$ are pentagonal. All four cells of the quartet 6.2 are hexagonal, as will be seen in Plate IV. Figs. 27–29, and 31. A comparison of the quartet 6.1 of Figure 27 with 5.4 of Figure 28 shows how little difference there is in the size of the cells of the two poles in the superficial view. In optical section, however, a distinct difference can be detected in the size of the deeper lying parts of these cells. In Figure 30 (Plate IV.) is represented such a section taken from the egg in the position shown in Figure 29. The section passes through the vertical axis in the plane corresponding to that of the paper in Figure 29, thus cutting the ventral cross furrow at right angles, and passing through the quadrants *b* and *d*. It will be seen that one of the two cells of the vegetative pole, labelled $d^{6.1}$ in the drawing, is much larger than the other, $b^{6.1}$. This is the cell which at the next generation gives rise to the first mesoderm cell, $d^{7.2}$, or *M*.

The generalization which Rabl made in his paper on Planorbis ('79), — "dass bei den Keimen mit reichlichem Nahrungsdotter von dem Zeitpunkte an, als Aequatorialfurchen auftreten, die Zellvermehrung in arithmetischer, bei den Keimen mit spärlichem Nahrungsdotter dagegen zuerst in arithmetischer, sodann aber in geometrischer Progression erfolgt," — is not borne out by the cleavage in Limax, as the twelve-cell stage does not regularly occur. The cleavage in Limax runs,

$$4 \;..\; 8 \;...\; 16 \;....\; 24 \;........\; 40.$$

or, $$(4) : (4) : (4) + (4) : (4) + (4) : (4) + (4) + (4) + (4).$$

This is fundamentally an arithmetical progression, a series whose common difference is four, the mathematical expression of the increase in the number of cells in the spiral type of cleavage. It varies, however, from the strict arithmetical series in that a multiple of the common difference is sometimes added as a result of the approximated or even synchronous division of two or more quartets. Thus the series may in some of its parts, like the twelve- to twenty-four-cell period of Planorbis, take the form of a geometrical series; but this is not fundamental, and, as Warneck in 1850 expressed the law, "In jedem Stadium des Furchungsprocesses entstehen nur vier Furchungskugeln, d. h. die Theilung geht nicht in einer geometrischen sondern einer arithmetischen Progression vor sich."

The general contour of the egg in the twenty-four-cell stages figured (Plate III. Figs. 23–25, Plate IV. Figs. 27–32, Plate IV. Figs. 33, 34) has been spherical, the transverse and vertical diameters being approximately the same. In the period leading up to this stage, however, eggs are found showing a considerable flattening in the dorso-ventral direction, i. e. a shortening of the vertical axis. In one egg showing the flattening, the dorso-ventral diameter was 70 $\mu$ and the transverse 120 $\mu$. This change may be dependent upon an elimination of such a cleavage cavity as is shown in Plate V. Fig. 34. A similar flattening is often found in those eggs in which the divisions leading to the forty-cell stage are taking place. These divisions will now be discussed. The order of their discussion does not, however, indicate their chronological succession.

### *Division of Quartet* 5.3, *forming* 6.5 *and* 6.6.

**Plate VI. Figs. 37, 39, 41.**

The division of this quartet does not take place, in some instances at least, until after the forty-cell stage; i. e. it is accompanied by divisions of the succeeding generation in other quartets. See Figures 39 and 41. In Figure 39 the cells $a^{5.3}$ and $d^{5.3}$ have divided, and $b^{5.3}$ is in a mitotic state, but $c^{5.3}$ is as yet undivided. In $b^{5.3}$ the end plates have been formed, but the cytoplasm is not yet constricted. The axis of the spindle lies parallel to the plane of the equator. There is every indication that the division is very nearly meridional. Figure 39 has forty-two cells; in Figure 41 there are forty-five cells; here, however, it is cells $a^{5.3}$ and $d^{5.3}$ that have but recently divided, the other cells of the quartet having evidently been divided for some time. Thus there is no constancy as to the sequence in which the cells of this quartet divide. In Figure 41 (Plate VI.) this division still shows some slight traces of a right spiral. Figure 37 (Plate VI.), a forty-cell stage, is described in my notes as containing the cells $a^{6.6}-d^{6.6}$, $a^{6.5}-d^{6.5}$, but owing to the rotundity and opacity of this egg the details in the periphery, i. e. the region of the cells in question, are very much obscured, and I consider this determination questionable.

The comparison of the division of this quartet with the corresponding one in Nereis is very interesting. In Nereis, as in Limax, the division is *nearly meridional*, and with traces of a right spiral. In this instance it takes place at the twenty-nine-cell stage, and the products form the *prototroch.* In Umbrella it does not take place till the sixty-five-cell stage, and here also exhibits an obscure right spiral. (See Tables of Cleavage, pp. 66, 74, and 75.)

### *Division of Quartet* 5.4, *forming* 6.7 *and* 6.8.

**Plate V. Figs. 35, 36; Plate VI. Figs. 37, 39, 41.**

This is one of the first divisions to follow the twenty-four-cell stage. Figures 35 and 36 (Plate V.) show it in progress; Figures 37, 39, and 41 after completion. It takes place in a very evident right spiral, the upper aster and derivative lying to the right in every case. The division is approximately equal, but is not synchronous in the different quadrants, as is shown in Figures 35 and 36. In Figure 35 all the cells of this quartet have divided except $a^{5.4}$; the quadrant $c$, judging from the size and position of the daughter nuclei, has evidently led in the division. In Figure 36, $b^{5.4}$ is the only one which has divided, resulting in $b^{6.7}$ and $b^{6.8}$, the other cells containing spindles. It is evident from these two cases that it is impossible to predicate any regular sequence in the successive divisions of the quadrants of this quartet.

This completes the discussion of the cleavages of this generation. It will be noted that all of the divisions clearly take place in a right spiral, with the exception of that of 5.3, and that this, though predominantly meridional, still shows traces of a right spiral.

## SEVENTH GENERATION. SIXTY-FOUR CELLS.

As was stated in my earlier paper ('94, p. 188), the divisions of this generation begin before those of the sixth are completed.

### *Division of Quartet* 6.1, *forming* 7.1 *and* 7.2.

**Plate VI. Figs. 38, 40, 42.**

The division of this quartet is the point of greatest interest in the cleavage, as it results in a differentiation of the germ layers, or at least in a separation of the primary mesoderm from the ect-entoderm.

In spite of the examination of a large number of eggs, and the repeated killing of those whose age and approximate stage were known, I have not been able as yet to obtain an egg showing the *spindles* resulting in this division. Figures 38, 40, and 42 (Plate VI.) all represent stages subsequent to the formation of $M$, and the other members of the quartet 7.2. There is some evidence, however, as to the character of the division. Figure 38 is a view of the vegetative pole of an egg of forty cells. The four central cells have *seven* peripheral neighbors. Deeper focusing reveals the presence of a large nucleus, lying within a definite cell boundary. This is quite below the level of the nuclei of the vegetative quartet. Its nucleus lies below and slightly nearer the median plane than that of $d^{7.1}$. The superficial extent of this deeper lying cell is limited to a narrow strip adjoining the cell with which it has arisen, i. e. it is peripheral to $d^{7.1}$. The other members of the quartet 7.2 are present, and when the test for the spiral is applied it is evident that this is a *left spiral, though the amount of the shifting* is evidently not very great. It is quite plain that in this case the cell $d^{7.2}$, which gives rise to the mesoderm, comes from $d^{6.1}$ at the time of its division into $d^{7.1}$ and $d^{7.2}$. As in previous stages, the quartets $d$ and $b$ are in contact at the ventral cross furrow.

Figure 40 (Plate VI.) represents a forty-two-cell stage which has recently been the scene of a number of divisions. Here, as in the egg just discussed, the cell $d^{7.2}$ is very large, and is crowded in toward the centre of the egg, lying below $d^{7.1}$ and slightly nearer the median plane. It maintains a small crescentic connection with the exterior, between $d^{7.1}$ and $d^{6.3}$. The other members of the quartet 7.2 are present, and show about the same nuclear conditions that $d^{7.2}$ ($= M$) does. They are therefore of about the same age. The divisions of the cells of the quartet 6.1 in this egg have evidently been very nearly equatorial, and unless there should be at a subsequent period some shifting of the mesoderm to a position nearer to the median plane, — as adopted in this paper, — it would be necessary to orient this egg as Rabl and Blochmann have oriented Planorbis and Neritina. Judging from the nuclear conditions the division has taken place quite recently. Eggs of later stages show that the mesoderm is generally placed bilaterally with reference to the cross furrows and the prevailing quadrangular form of the egg of those stages. The division of this quartet is in all cases unequal, the smaller cells lying at the vegetative pole.

The conditions of the egg shown in Figure 42 (Plate VI.) were for a long time very puzzling to me. It contains forty-five cells, which readily group themselves into quartets. A median deep-lying mesoderm cell is present, as in the egg last described, but the relations of the cells of the quartet of the vegetative pole to this cell and to one another are different from those of the other eggs, in the following respect: the cells which meet in the ventral cross furrow are $a^{7.1}$ and $c^{7.1}$, instead of $d^{7.1}$ and $b^{7.1}$, as in the other two eggs figured. Repeated trials failed to give any other solution which would accord with the conditions in the other parts of the egg. The juxtaposition of the quadrants *a* and *c* occurs normally in the reversed type of cleavage (see Figs. C and D,* p. 53), and the possibility is at once suggested that this egg may have had reversed rather than unreversed or normal cleavage. Other parts of the egg, however, furnish no corroborative evidence, and the suggestion must be dismissed. I believe, then, that owing to some cause, mechanical or other, a change in the normal relations of the cells of the quartet to one another has been brought about. This has naturally raised the question as to the constancy of the cross furrows, upon which the orientation of the egg so largely depends. This case in Limax is not an isolated one, for in Nereis, where, as has already been pointed out, the dorsal furrow is formed in the early stages of cleavage by the apposition of the quadrants *a* and *c*, we find this normal arrangement disturbed in one instance, the furrows being formed by the quadrants *b* and *d* (Wilson '92, Plate XIV. Fig. 19, p. 390). In the later stages, i. e. after the cells of the seventh generation appear at the animal pole, the dorsal cross furrow is normally formed by the apposition of *b* and *d*, but in one case (Wilson *l. c.*, Plate XVI. Fig. 35) we find this arrangement disturbed, the cross furrow being formed by *a* and *c*. This disturbance is also accompanied by the mitotic conditions of neighboring cells.

Another case occurs in Neritina (Blochmann '81, Taf. VII. Figs. 51, 53, 56), in which two eggs — one a thirty-six-, the other a forty-cell stage — present cross furrows formed by the apposition of different pairs of quadrants. There is not here, as in Nereis, an intervening mitosis to explain the disturbance of the customary order.

In Lang's ('85) Taf. 34, Figs. 14, 15, we find a similar transposition from the usual arrangement of the apical quartet, accompanied in this case by mitosis in adjoining cells. In view of these cases it seems not improbable that there has been in this Limax egg a disarrangement of the normal condition at the vegetative pole, as a result perhaps of the recent divisions at that pole, the collapse of the cleavage cavity, or some other mechanical disturbance.

It seems almost certain that the primary mesoderm cell, $d^{7.2}$ ($M$), is formed synchronously with the other members of the quartet to which it belongs. In this respect Limax stands in sharp contrast to Nereis, where the primary mesoderm cell originates at the thirty-eight-cell stage, but the cleavage of the remaining cells of the quartet is long delayed. Also in Umbrella there is a corresponding lack of synchronism, for the division of this quartet commences with the formation of $d^{7.2}$ at the twenty-five-cell stage, but is not completed until the forty-seven-cell stage is reached. Likewise in Planorbis the formation of the primary mesoblast antedates the cleavage of the other cells of the same quartet.

### *Division of Quartet* 6.2, *forming* 7.3 *and* 7.4.

**Plate IV. Figs. 31, 32; Plate V. Fig. 35; Plate VI. Figs. 38, 40.**

The spindles resulting in this division are among the first to appear in the twenty-four-cell stage. Figures 31 and 32 (Plate IV.) show spindles in all of the cells of this quartet except $a^{6.2}$, and in this the stages preparatory to the formation of the spindle are seen (Fig. 31). The nucleus is very large; the chromatic granules are distributed in a network, and the nuclear membrane is still intact. At diametrically opposite sides of the nucleus, in the long axis of the cell, and closely applied to the nuclear membrane, there are two large, clear spherical spaces in the cytoplasm, bounded by a granular zone. These structures are probably the astrocœls of Fol ('91). The surface of the nucleus presents on one side a peculiar constriction, or crease, running between the two astrocœls, as though they were connected by a strand of substance (central spindle) which was compressing the thin nuclear membrane.

The spindles in this quartet, as shown in Figures 31 and 32 (Plate IV.) are almost free from any inclination indicative of a spiral arrangement. The one in $b^{6.2}$ shows traces of a right spiral, but there is indication from the position of the spindles that the division will be equatorial rather than oblique; such indeed is the character of the division, as is shown in $c^{7.3}$, $c^{7.4}$, Figure 35 (Plate V.). The order of nuclear advancement in this quartet as shown in Figure 32 (Plate IV.), is *b*, *d*, *c*, *a*, but in Figure 35 (another egg) the cell *c* has been the first to divide, whereas in Figure 38 (Plate VI.), a forty-cell stage, the cell $d^{6.2}$ is just dividing, it being the last of its quartet to undergo the process. This seems to show either that the cleavage in this quartet progresses very slowly, or, what is more probable, that there is considerable variation in the sequence in which its components divide. In the case of Figure 38 (Plate VI.) there is strong indication of a *left* spiral; so also a slight indication of the same in Figure 40, $a^{7.3}$, $a^{7.4}$. In all the other figures the division seems to be *equatorial.* A comparison with Nereis reveals in this instance the same marked agreement noted for the meridional cleavage of the quartet 5.3. In Umbrella this division takes place at the twenty-nine-cell stage, and is also equatorial.

### *Division of Quartet* 6.3, *forming* 7.5 *and* 7.6.

**Plate VI. Figs. 41, 42.**

This division is in progress in the quadrant *c* in Figures 41, 42, and the other members of the quartet are also approaching mitosis. There is a faint trace of a *left* spiral to be detected in the position of $c^{7.5}$ and $c^{7.6}$ of Figure 41, but the division is predominantly equatorial.

### *Division of Quartet* 6.4, *forming* 7.7 *and* 7.8.

**Plate VI. Figs. 39, 40, 41, 42.**

In the two eggs figured the spiral is clearly shown by the relative position of the nuclei to be a *left* spiral. Thus all the spirals of this seventh generation, wherever they have been traced, have been *left* spirals.

With this forty-five-cell stage my detailed account of the cleavage closes. I have not been able to decipher satisfactorily the conditions in the eggs of the next stage, because during this stage a large number of cells divide, — in one instance as many as thirteen. Moreover, the rounded contours of the mitotic cells produce such changes in the surface of the egg as effectually to obscure all trace of its poles, and the absence of polar globules, of macromeres, or of any "landmarks" whatever for orientation, makes any interpretation of these later stages at the best provisional, and very largely conjectural. Added to these difficulties is that produced by the vacuolation which prevailed in a very large proportion of the eggs which I have examined. This distorts and obscures the relation of cells to such an extent as to make a determination of their lineage extremely difficult, if not impossible.

As late, however, as the hundred-cell stage, when four mesoderm cells are present, it is possible on favorable eggs to work out a provisional lineage, but I have not as yet succeeded in connecting this with the forty-five-cell stage.

Thus the outcome of my work as a study in *cell lineage* is a disappointment, for I have not been able to trace a single blastomere to a definite organ of the adult. At the stage of thirty-eight cells in Nereis, Wilson was able to assign a definite fate to each blastomere; but in Limax there is no trace, save in the early differentiation of the mesoderm, of that precocious development so marked in Nereis. This fact makes the identity of the cleavage of Limax with that of Nereis all the more wonderful and difficult to explain.

I insert here (p. 66) a table of the cleavage of Limax, so far as I have followed it, which epitomizes the foregoing discussion of the alternation of spirals in successive generations of cells. The spirals, wherever they occur, conform to the law of alternation as defined in my former paper ('94, p. 189).

### C. Literature on Spiral Cleavage.

The conformity of other animals to the law of spiral cleavage has in all cases been obscured by the systems of nomenclature employed. Since no one of my predecessors has formulated this supposed law, it of course has not been tested on any of the forms whose cleavage has been worked out. It has seemed desirable, therefore, to go over the available literature and point out those cases which agree, and those which seem to disagree with my proposition.

In order that the subject may be treated in as brief a form as possible the discussion of each case is accompanied by a tabulated presentation of the cleavage, in which the author's designation of cells and spirals is joined in parallel columns with the designation which my system would impose.

In my former paper ('94, pp. 192–196) the conformity of the cleavage of Neritina, as described by Blochmann ('81), to the alternation of spirals was discussed, and the cleavage tabulated. In what follows I have discussed all other cases which seemed worthy of consideration in this connection.

Fol states ('75, p. 117) that Clio likewise has the same regular cleavage as Cavolina, and his few figures of the early stages of this form suggest that the cleavage is of the normal type. Cymbulia also seems to conform to this type.

The cleavage of the Heteropods, which he ('76) states is identical with that of the Pteropods, is, according to his figures, of two types: Firoloides (Plate I. Figs. 1–3) presenting the normal type, Pterotrachea (Plate IV. Figs. 5, 6) the reversed type, *if his labelling, indicating the lineage, is correct.* There is evidence, however, that some of the divisions belong to the normal type (Plate IV. Fig. 9).

## CLEAVAGE OF LIMAX.

| Generation. | Number of Cells. | Designation of Cells. | Spirals. |
|---|---|---|---|
| VII. | 40 | $a^{6.4} < \left.\begin{matrix} a^{7.8} \\ a^{7.7} \end{matrix}\right\}$ | Left. |
| | 48 | $a^{6.3} < \left.\begin{matrix} a^{7.6} \\ a^{7.5} \end{matrix}\right\}$ | Left, — cleavage nearly equatorial. |
| | 28 | $a^{6.2} < \left.\begin{matrix} a^{7.4} \\ a^{7.3} \end{matrix}\right\}$ | Left, — cleavage nearly equatorial. |
| | 36 | $a^{6.1} < \left.\begin{matrix} a^{7.2} \\ a^{7.1} \end{matrix}\right\}$ | Left. |
| VI. | 32 | $a^{5.4} < \left.\begin{matrix} a^{6.8} \\ a^{6.7} \end{matrix}\right\}$ | Right. |
| | 44 | $a^{5.3} < \left.\begin{matrix} a^{6.6} \\ a^{6.5} \end{matrix}\right\}$ | Right, — cleavage nearly meridional. |
| | 24 | $a^{5.2} < \left.\begin{matrix} a^{6.4} \\ a^{6.3} \end{matrix}\right\}$ | Right. |
| | 20 | $a^{5.1} < \left.\begin{matrix} a^{6.2} \\ a^{6.1} \end{matrix}\right\}$ | Right. |
| V. | 16 | $a^{4.2} < \left.\begin{matrix} a^{5.4} \\ a^{5.3} \end{matrix}\right\}$ | Left |
| | 12 | $A^{4.1} < \left.\begin{matrix} a^{5.2} \\ a^{5.1} \end{matrix}\right\}$ | Left. |
| IV. | 8 | $A < \left.\begin{matrix} a^{4.2} \\ A^{4.1} \end{matrix}\right\}$ | Right. |
| III. | 4 | $A, B, C, D.$ | Left. |
| II. | 2 | $\overline{AB}, \overline{CD}.$ | |
| I. | 1 | Ovum. | |

As stated in my earlier paper ('94, p. 191), there are some indications in Rabl's work that Planorbis presents a case of reversed cleavage, i. e. the cleavage is such that the spirals of the even generations are left, and those of the odd right. Fol's ('80) figures of the eight- and sixteen-cell stages of this Pulmonate (Plate IX.–X. Figs. 1, 2) indicate that the spiral of the fourth generation is a left one, and that of the fifth a right one. My own sketches of Planorbis, made from living eggs in the spring of 1892, show the same direction in these spirals. So far as can be judged from these facts, the alternation of spirals holds in this case, which is probably one of reversed cleavage.

CLEAVAGE OF CAVOLINA.

Fol ('75).

| Fol's Nomenclature. | | Generation. | Number of Cells. | Revised Nomenclature. | |
|---|---|---|---|---|---|
| Spirals.[1] | Cells. | | | Cells. | Spirals. |
| Left. | $\begin{matrix} I' \\ I'' \end{matrix} > I'$ | VI. | 20 | $a^{5.2} < \begin{matrix} a^{6.4} \\ a^{6.3} \end{matrix}$ | Right. |
| Right. | $\begin{matrix} 1 \\ 1' \end{matrix} > 1$ | V. | 16 | $a^{4.2} < \begin{matrix} a^{5.4} \\ a^{5.3} \end{matrix}$ | Left. |
| Left. | $\begin{matrix} I' \\ I \end{matrix} > I$ | | 12 | $A^{4.1} < \begin{matrix} a^{5.2} \\ a^{5.1} \end{matrix}$ | Left. |
| Right. | $\begin{matrix} 1 \\ I \end{matrix} > I$ | IV. | 8 | $A < \begin{matrix} a^{4.2} \\ A^{4.1} \end{matrix}$ | Right. |
| | *I, II, III, IV.* | III. | 4 | *A, B, C, D.* | Left.<br>Division oblique, cells in one plane. |

If the reversed spirals persist until the formation of the mesoderm, this germ layer would then come from the *right* posterior macromere, instead of the left posterior one, i. e. if we adopt Wilson's orientation instead of Rabl's. In the table given above it will be noticed that the mesoderm cell *M* is placed as a member of the basal quartet of the sixth generation. It should be remembered, however, that Rabl in a later paper ('80) revised this earlier opinion as to the origin of the mesoderm cell, deriving it this time by division from the cell *M* of the above table. According to this the mesoderm cell in Planorbis, as in many other forms, belongs to the quartet 7.2. It seems to me that the orientation of the stages of Planorbis previous to the formation of the mesoderm is still an open question. As I have stated in the discussion of Limax, the orientation

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[1] Fol does not name or discuss spirals. The nomenclature in this column is deduced entirely from his lettering of the cells. After the third generation the divisions of only one quadrant (*I*) are followed. In this, as in the following tables, capital letters indicate macromeres, and the lineage of only a single quadrant (*a* of the revised nomenclature) is given.

## CLEAVAGE OF PLANORBIS.

Rabl ('79).

| Rabl's Nomenclature. | Generation. | Number of Cells. | Revised Nomenclature. | |
|---|---|---|---|---|
| Cells. | | | Cells. | Spirals. |
| $\left.\begin{matrix} E_5 & E_6 & E_7 & E_8 \\ E_{17} & E_{18} & E_{19} & E_{20} \end{matrix}\right\}$ | VI. | 24 | $a^{5.2} < \begin{matrix} a^{6.4} \\ a^{6.3} \end{matrix}$ | Left ? |
| $\left.\begin{matrix} E_{13} & E_{14} & E_{15} & E_{16} \\ EJ_1 & EJ_2 & EJ_3 & M \end{matrix}\right\}$ | | 24 | $A^{5.1} < \begin{matrix} a^{6.2} \\ A^{6.1} \end{matrix}$ | Left. |
| $\left.\begin{matrix} E_1 & E_2 & E_3 & E_4 \\ E_{12} & E_9 & E_{10} & E_{11} \end{matrix}\right\}$ | V. | 24 | $a^{4.2} < \begin{matrix} a^{5.4} \\ a^{5.3} \end{matrix}$ | Right. |
| $\left.\begin{matrix} E_6 & E_7 & E_8 & E_5 \\ EJ_1 & EJ_2 & EJ_3 & ME \end{matrix}\right\}$ | | 12 | $A^{4.1} < \begin{matrix} a^{5.2} \\ A^{5.1} \end{matrix}$ | Right. |
| $\begin{matrix} E_1 & E_2 & E_3 & E_4 \\ EJ_1 & EJ_2 & EJ_3 & ME \end{matrix}$ | IV. | 8 | $A < \begin{matrix} a^{4.2} \\ A^{4.1} \end{matrix}$ | Left. |
| $EJ_1\ EJ_2\ EJ_3\ ME$ | III. | 4 | $A, B, C, D.$ | Right. |
| | II. | 2 | $\overline{AB}, \overline{CD}.$ | |
| | I. | 1 | Ovum. | |

of the early stages depends on the estimated amount of shifting of the mesoderm cell upon the basal quartet $a^{7.1}$ — $d^{7.1}$. There is evidence in Rabl's figures ('80, Taf. XXIX. Figg. 2, 3, 4) that there is at least some shifting, but whether it is sufficient to justify an orientation similar to that adopted by Wilson for Nereis cannot be decided from the evidence at hand. It is however sufficient to raise the question as to the correctness of Rabl's orientation.

In Planorbis the asymmetry of the adult is sinistral; so also in Physa heterostropha, whose segmentation likewise shows the same phenomenon of reversed cleavage, as I can affirm from my own observations on the living egg.[1] In my former paper ('94, p. 191) I called attention to the fact that Haddon ('82, Plate XXXI. Fig. 6) figures a four- to eight-cell stage of Janthina which apparently presents a left spiral, i. e. the reverse of that found in a corresponding stage of Limax and other dextral forms. But according to Fischer ('80–87, p. 775) Janthina is a *dextral* form. These cases of Planorbis, Physa, and Janthina at once raise a most interesting question as to the relation that may exist between the two forms of cleavage, normal and reversed, and the dextral or sinistral asymmetry of the adult. The occurrence of reversed cleavage in these two sinistral forms is suggestive of a causal relation between the conditions of the embryo and the adult, but the existence of this one observation of Haddon's is sufficient to throw much doubt on that conclusion. There remains the possibility that on renewed examination the cleavage of Janthina may prove to be normal, and that this case of Haddon's may be referred to a chance sinistral form. In answer to an inquiry of mine, Dr. J. I. Peck of Williams College has kindly written, "I have never seen a sinistral Janthina; all of those which came under my observation ('93) were dextral: all of those in our collection here are dextral also, as were those I saw at the Museum at Yale. These were of four species, I think, and collected at different points of the Atlantic and Pacific, both Arctic and Tropical. I have, however, probably not seen enough material to expect a sinistral individual." Of the two or three hundred shells of Janthina, representing several species, in the Museum collection, not one is sinistral.

The data for the discussion of this interesting question are as yet too scanty to justify any generalizations. The examination of the cleavage in such genera as Fulgur and Achatinella, which contain both dextral and sinistral forms, as well as that of heterostrophic species, ought to be decisive upon this point, where we have as yet so little light.

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[1] Consult also the Addendum, page 111.

## CLEAVAGE OF APLYSIA.

Blochmann ('83).

| Blochmann's Nomenclature. | | Generation. | Number of Cells. | Revised Nomenclature. | |
|---|---|---|---|---|---|
| Spirals. | Cells. | | | Cells. | Spirals. |
| — | $> b_2'$ | VII. | — | $a^{6.3} < \begin{matrix} a^{7.6} \\ a^{7.5} \end{matrix}$ | Left. |
| — | $\begin{matrix} b_3' \\ b_3 \end{matrix} > b_3$ | | — | $a^{6.2} < \begin{matrix} a^{7.4} \\ a^{7.3} \end{matrix}$ | Meridional, slightly left. |
| — | $> b$ | | — | $A^{6.1} < \begin{matrix} a^{7.2} \\ A^{7.1} \end{matrix}$ | Left. |
| — | $\begin{matrix} b_2 \\ b_2' \end{matrix} > b_2$ | VI. | 20 | $a^{5.2} < \begin{matrix} a^{6.4} \\ a^{6.3} \end{matrix}$ | Right. |
| — | $\begin{matrix} b_3 \\ b \end{matrix} > b$ | | 20 | $A^{5.1} < \begin{matrix} a^{6.2} \\ A^{6.1} \end{matrix}$ | Right. |
| Left. | $\begin{matrix} b_2 \\ b \end{matrix} > b$ | V. | 12 | $A^{4.1} < \begin{matrix} a^{5.2} \\ A^{5.1} \end{matrix}$ | Left. |
| Right. | $\begin{matrix} b_1 \\ b \end{matrix} > b$ | IV. | 8 | $A < \begin{matrix} a^{4.2} \\ A^{4.1} \end{matrix}$ | Right. |
| | $b, a, d, c.$ | III. | 4 | $A, B, C, D.$ | Left. |
| | $A', A.$ | II. | 2 | $\overline{AB}, \overline{CD}.$ | |

In the above table the labelling of cells indicated in the second column is that given by Blochmann to cells which seem to be homologous with those of quadrant $A$.

The cleavage of Aplysia, so far as followed by Blochmann, resembles very closely that of Umbrella. If we interpret the cleavage as Heymons has that of Umbrella, we find that here also the posterior and smaller cell of the two-cell stage divides first; the mesoderm quadrant $D$

(labelled *c* by Blochmann) also precedes in some instances in the later divisions. The yolk, however, is confined mainly to two of the macromeres, *A* and *B*, instead of being lodged principally in three, *A*, *B*, and *C*, as it is in Umbrella.

All attempts to reconcile the cleavage of Chiton, as described by Kowalevsky ('83) and Metcalf ('93), with the alternation of spirals shown in other forms of Molluscan cleavage are involved in serious difficulties. Unfortunately neither author figures nuclei or spindles, with the exception of one figure in each paper. The relationship of cells and the direction of the spiral is also explicitly stated in certain cases to be a *matter of conjecture* on their part. Therefore it does not seem profitable for me to add to their conjectures others of my own. It is however possible to force upon the cleavage of Chiton, as figured by these authors, an interpretation which causes it to accord with the spiral type of cleavage, but this interpretation meets a serious obstacle in the sixteen-cell stage, though it does not violate the relationships of cells in the few cases where these authors have indicated relationships by nuclear conditions (Kowalevsky, Plate I. Fig. 7, Metcalf, Plate XV. Fig. xvii.).

I do not wish to commit myself to the view that Chiton conforms to that type, for, as Metcalf has suggested, " most of the divisions are of the radial type." The distribution of the yolk in the blastomeres is also suggestive of the radial type. There are, however in Kowalevsky's figures (Plate I. Figs. 4–13) many suggestions of spiral cleavage. In Metcalf's figures, on the other hand, " individual variations in the shape of the blastomeres are not preserved. The figures show what may be called the typical condition." Thus most of the evidence of spiral cleavage, if such exists, must be eliminated from his figures.

The cleavage of Discocœlis conforms to the spiral type and the alternation of spirals, with the possible exception of the spiral of 7.15–7.16, to which reference was made in my former paper ('94, p. 196). It is necessary to relabel Figure 6 of Lang's Tafel XXXV., in order to reconcile it with the apical views which he has given of the same stage, and also with the principle of alternation.

The conformity of the cleavage of Nereis to the law of alternation of spirals is perfect, as is demonstrated by the application of the uniform system of naming spirals in the above table. Even in those cleavages designated as equatorial or meridional, traces of the spiral characteristic of the generation can often be detected.

The Nereis table is marked by the abrupt termination of the spiral

## CLEAVAGE OF DISCOCŒLIS.

Lang ('85).

| LANG'S NOMENCLATURE. | | Generation. | Number of Cells. | REVISED NOMENCLATURE. | |
|---|---|---|---|---|---|
| Spirals. | Cells. | | | Cells. | Spirals. |
| Left. | $\begin{matrix}ae_1\\ae_6\end{matrix}>ae_1$ | VII. | 44 | $a^{6.8}<\begin{matrix}a^{7.16}\\a^{7.15}\end{matrix}$ | Right, contradicts law of alternation. |
| — | $\begin{matrix}ae_5\\ae_3\end{matrix}>ae_3$ | | 40 | $a^{6.7}<\begin{matrix}a^{7.14}\\a^{7.13}\end{matrix}$ | Left? |
| — | $\begin{matrix}am_3\\am_1\end{matrix}>am_1$ | | 52 | $a^{6.4}<\begin{matrix}a^{7.8}\\a^{7.7}\end{matrix}$ | Left. |
| Right. | $\begin{matrix}a\\auen\end{matrix}>a$ | | 32 | $A^{6.1}<\begin{matrix}A^{7.2}\\a^{7.1}\end{matrix}$ | Left. |
| Left. | $\begin{matrix}ae_1\\ae_3\end{matrix}>ae_1$ | VI. | 28 | $a^{5.4}<\begin{matrix}a^{\;.8}\\a^{6.7}\end{matrix}$ | Right. |
| Left. | $\begin{matrix}ae_2\\ae_4\end{matrix}>ae_2$ | | 36 | $a^{5.3}<\begin{matrix}a^{6.6}\\a^{6.5}\end{matrix}$ | Right. |
| Right. | $\begin{matrix}am_1\\am_2\end{matrix}>am_1$ | | 24 | $a^{5.2}<\begin{matrix}a^{6.4}\\a^{6.3}\end{matrix}$ | Right. |
| Right. | $\begin{matrix}a_2m_1\\a\end{matrix}>a$ | | 20 | $A^{5.1}<\begin{matrix}a^{6.2}\\A^{6.1}\end{matrix}$ | Right. |
| Right. | $\begin{matrix}ae_1\\ae_2\end{matrix}>ae_1$ | V. | 16 | $a^{4.2}<\begin{matrix}a^{5.4}\\a^{5.3}\end{matrix}$ | Left. |
| Left. | $\begin{matrix}am_1\\a\end{matrix}>a$ | | 12 | $A^{4.1}<\begin{matrix}a^{5.2}\\A^{5.1}\end{matrix}$ | Left. |
| Right. | $\begin{matrix}ae_1\\a\end{matrix}>a$ | IV. | 8 | $A<\begin{matrix}a^{4.2}\\A^{4.1}\end{matrix}$ | Right. |
| Left. | $a, b, c, d.$ | III. | 4 | $A, B, C, D.$ | Left. |
| | | II. | 2 | $\overline{AB}, \overline{CD}.$ | |

## CLEAVAGE OF NEREIS.

Wilson ('92).

| WILSON'S NOMENCLATURE. | | Generation. | Number of Cells. | REVISED NOMENCLATURE. | |
|---|---|---|---|---|---|
| Spirals. | Cells. | | | Cells. | Spirals. |
| Left. | $\begin{matrix}a^{1.3}\\a^{1}\end{matrix}>a^{1}$ | VII. | 36 | $a^{6.8}<\begin{matrix}a^{7.16}\\a^{7.15}\end{matrix}$ | Left, *c* and *d* precede. |
| Left. | $\begin{matrix}a^{1.2.2}\\a^{1.2.1}\end{matrix}>a^{1.2}$ | | — | $a^{6.7}<\begin{matrix}a^{7.14}\\a^{7.13}\end{matrix}$ | Left. |
| Horizontal. | $\begin{matrix}a^{1.1.2.2}\\a^{1.1.2.1}\end{matrix}>a^{1.1.2}$ | | 42–58 | $a^{6.6}<\begin{matrix}a^{7.12}\\a^{7.11}\end{matrix}$ | Equatorial. |
| Vertical. | $\begin{matrix}a^{1.1.1.2}\\a^{1.1.1.1}\end{matrix}>a^{1.1.1}$ | | 42–58 | $a^{6.5}<\begin{matrix}a^{7.10}\\a^{7.9}\end{matrix}$ | Meridional. |
| — | $\begin{matrix}X\\x^{2}\end{matrix}>X$ | | 37 + | $d^{6.4}<\begin{matrix}d^{7.8}\\d^{7.7}\end{matrix}$ | Left, *d* precedes. |
| Horizontal. | $>a^{2.2}$ | | — | $a^{6.3}<\begin{matrix}a^{7.6}\\a^{7.5}\end{matrix}$ | Equatorial. |
| Horizontal. | $>a^{3}$ | | — | $a^{6.2}<\begin{matrix}a^{7.4}\\a^{7.3}\end{matrix}$ | Equatorial. |
| Left. | $\begin{matrix}M\\D\end{matrix}>D$ | | 38 + | $D^{6.1}<\begin{matrix}d^{7.2}=M\\D^{7.1}\end{matrix}$ | Left, *D* precedes. |
| Left. | $\begin{matrix}a^{1}\\a^{1.2}\end{matrix}>a^{1}$ | VI. | 20 | $a^{5.4}<\begin{matrix}a^{6.8}\\a^{6.7}\end{matrix}$ | Right. |
| Meridional. | $\begin{matrix}a^{1.1.2}\\a^{1.1.1}\end{matrix}>a^{1.1}$ | | 29 | $a^{5.3}<\begin{matrix}a^{6.6}\\a^{6.5}\end{matrix}$ | Right, approaching meridional. |
| Left. | $\begin{matrix}a^{2.2}\\a^{2.1}\end{matrix}>a^{2}$ | | 23–32 | $a^{5.2}<\begin{matrix}a^{6.4}\\a^{6.3}\end{matrix}$ | Right, *d* precedes. |
| Right. | $\begin{matrix}a^{3}\\A\end{matrix}>A$ | | 23–29 | $A^{5.1}<\begin{matrix}a^{6.2}\\A^{6.1}\end{matrix}$ | Right, *C* and *D* precede. |
| Right. | $\begin{matrix}a^{1}\\a^{1.1}\end{matrix}>a^{1}$ | V. | 16 | $a^{4.2}<\begin{matrix}a^{5.4}\\a^{5.3}\end{matrix}$ | Left. |
| Left. | $\begin{matrix}a^{2}\\A\end{matrix}>A$ | | 16 | $A^{4.1}<\begin{matrix}a^{5.2}\\A^{5.1}\end{matrix}$ | Left, *D* precedes. |
| Right. | $\begin{matrix}a^{1}\\A\end{matrix}>A$ | IV. | 8 | $A<\begin{matrix}a^{4.2}\\A^{4.1}\end{matrix}$ | Right, *C* and *D* precede. |
| | *A*, *B*, *C*, *D*. | III. | 4 | *A*, *B*, *C*, *D*. | Left. |
| | $\overline{AB}$, $\overline{CD}$. | II. | 2 | $\overline{AB}$, $\overline{CD}$. | |

## CLEAVAGE OF UMBRELLA.

Heymons ('93).

| Heymons's Nomenclature. | | Generation. | Number of Cells. | Revised Nomenclature. | |
|---|---|---|---|---|---|
| Spirals. | Cells. | | | Cells. | Spirals. |
| —— | $\begin{smallmatrix}a''_{1.3}\\ a''_{1}\end{smallmatrix} > a''_{1}$ | IX. | 75 | $a^{8.14} < \begin{smallmatrix}a^{9.28}\\ a^{9.27}\end{smallmatrix}$ | Meridional. |
| Right. | $\begin{smallmatrix}a''_{1.2}\\ a''_{1.2.1}\end{smallmatrix} > a''_{1.2}$ | | 79 | $a^{8.13} < \begin{smallmatrix}a^{9.26}\\ a^{9.25}\end{smallmatrix}$ | Left. |
| —— | $\begin{smallmatrix}a''_{1}\\ a''_{1.2}\end{smallmatrix} > a''_{1}$ | VIII. | 51 | $a^{7.7} < \begin{smallmatrix}a^{8.14}\\ a^{8.13}\end{smallmatrix}$ | Equatorial, trace of right. |
| —— | $\begin{smallmatrix}a''\\ a''_{3}\end{smallmatrix} > a''$ | | 55 | $a^{7.6} < \begin{smallmatrix}a^{8.12}\\ a^{8.11}\end{smallmatrix}$ | Equatorial. |
| Left, *a* and *b*.<br>Merid., *c* and *d*. | $\begin{smallmatrix}a'''\\ a'''_{2}\end{smallmatrix} > a'''$ | | 40–59 | $a^{7.4} < \begin{smallmatrix}a^{8.8}\\ a^{8.7}\end{smallmatrix}$ | Right, *a* and *b*.<br>Merid., *c* and *d*. |
| Meridional. | $\begin{smallmatrix}a'''_{1}\\ a'''_{1.1}\end{smallmatrix} > a'''_{1}$ | | 67 | $a^{7.3} < \begin{smallmatrix}a^{8.6}\\ a^{8.5}\end{smallmatrix}$ | Meridional, *a* and *b* precede. |
| —— | $\begin{smallmatrix}A''\\ A\end{smallmatrix} > A$ | | 91 + | $A^{7.1} < \begin{smallmatrix}A^{8.2}\\ A^{8.1}\end{smallmatrix}$ | Bilateral, trace of right. |
| Like Nereis. | Not figured. | VII. | 91 + | $a^{6.8} < \begin{smallmatrix}a^{7.16}\\ a^{7.15}\end{smallmatrix}$ | Left. |
| Right. | $\begin{smallmatrix}a'_{2}\\ a'_{2.1}\end{smallmatrix} > a'_{2}$ | | 71 | $a^{6.7} < \begin{smallmatrix}a^{7.14}\\ a^{7.13}\end{smallmatrix}$ | Left. |
| Left. | $\begin{smallmatrix}a_1''{}^{.1}\\ a_1''\end{smallmatrix} > a''_{1}$ | | 33 | $a^{6.4} < \begin{smallmatrix}a^{7.8}\\ a^{7.7}\end{smallmatrix}$ | Left, *b* and *c* precede. |
| Left. | $\begin{smallmatrix}a''\\ a''_{2}\end{smallmatrix} > a''$ | | 37 | $a^{6.3} < \begin{smallmatrix}a^{7.6}\\ a^{7.5}\end{smallmatrix}$ | Left, *b* and *d* precede. |
| Left. | $\begin{smallmatrix}a'''\\ a'''_{1}\end{smallmatrix} > a'''$ | | 29 | $a^{6.2} < \begin{smallmatrix}a^{7.4}\\ a^{7.3}\end{smallmatrix}$ | Equatorial, trace of left. |
| Left. | $\begin{smallmatrix}A'\\ A\end{smallmatrix} > A$ | | 25–47 | $A^{6.1} < \begin{smallmatrix}A^{7.2}\\ A^{7.1}\end{smallmatrix}$ | Left, *D* precedes. |
| Left. | $\begin{smallmatrix}a'\\ a'_{2}\end{smallmatrix} > a'$ | VI. | 44 | $a^{5.4} < \begin{smallmatrix}a^{6.8}\\ a^{6.7}\end{smallmatrix}$ | Right. |
| Right. | $\begin{smallmatrix}a'_{1}\\ a'_{1.1}\end{smallmatrix} > a_1'$ | | 65 | $a^{5.3} < \begin{smallmatrix}a^{6.6}\\ a^{6.5}\end{smallmatrix}$ | Equatorial, approaching bilateral, *c* and *d* precede. |
| Right. | $\begin{smallmatrix}a''_{1}\\ a''\end{smallmatrix} > a''$ | | 24 | $a^{5.2} < \begin{smallmatrix}a^{6.4}\\ a^{6.3}\end{smallmatrix}$ | Right. |
| Right. | $\begin{smallmatrix}a'''\\ A\end{smallmatrix} > A$ | | 16 | $A^{5.1} < \begin{smallmatrix}a^{6.2}\\ A^{6.1}\end{smallmatrix}$ | Right, *C* and *D* precede. |
| Right. | $\begin{smallmatrix}a'\\ a'_{1}\end{smallmatrix} > a'$ | V. | 20 | $a^{4.2} < \begin{smallmatrix}a^{5.4}\\ a^{5.3}\end{smallmatrix}$ | Left. |
| Left. | $\begin{smallmatrix}a''\\ A\end{smallmatrix} > A$ | | 12 | $A^{4.1} < \begin{smallmatrix}a^{5.2}\\ A^{5.1}\end{smallmatrix}$ | Left. |
| Right. | $\begin{smallmatrix}a'\\ A\end{smallmatrix} > A$ | IV. | 8 | $A < \begin{smallmatrix}a^{4.2}\\ A^{4.1}\end{smallmatrix}$ | Right. |
| Left. | *A*, *B*, *C*, *D*. | III. | 4 | *A*, *B*, *C*, *D*. | Left. |
| | $\overline{AB}$, $\overline{CD}$. | II. | 2 | $\overline{AB}$, $\overline{CD}$. | $\overline{CD}$ precedes. |

period in the seventh generation. The cleavages of the following generations are meridional or equatorial, and belong to the bilateral period. Another noticeable feature is the general precedence of the mesoderm-producing quadrant *d* in the cleavages of the various quartets.

The bilateral period in the cleavage of Umbrella is not so sharply marked off from the spiral period as it is in Nereis; in Umbrella spiral cleavage occurs as late as the ninth generation. In Nereis it ceases in the seventh. The quartets 5.3 and 6.2 *in both forms* are the ones in which the spiral character of the division first gives way to the meridional and equatorial cleavage, — characteristic of the bilateral period.

The cleavage of Umbrella, like that of Nereis, presents no contradictions to the law of alternation of spirals. This striking agreement of Nereis, Umbrella, and Limax must far outweigh any seeming contradiction arising in the work of the earlier writers upon spiral cleavage. It is only necessary to apply the proposed system of nomenclature to the careful work of Wilson and Heymons to make clear at once that the alternation defended holds good. The system of nomenclature employed in this paper facilitates the demonstration of the alternation of spirals in successive generations of cells; but the alternation itself is a factor independent of mere names. It is the fundamental basis of the so called "spiral type" of cleavage. A recognition of this fact might well be embodied in nomenclature, and *alternating cleavage* substituted for the ambiguous and misleading term "spiral cleavage."

## D. The Mesoderm.

In the forty-four-cell stage, at which the discussion of the cleavage of Limax was dropped, the germ layers are already differentiated. The quartets 7.3, 7.4, 6.3, 7.7, 7.8, 6.5, 6.6, 6.7, 6.8, are pure *ectoderm*, the quartet 7.1 and three fourths of the quartet 7.2, viz. $a^{7.2}$, $b^{7.2}$, and $c^{7.2}$, are *entoderm*, while $d^{7.2}$ is the sole representative of the *middle germ layer*.

The seven entoderm cells and their progeny come to lie in the region of the blastopore, and with the invagination are carried in to form the lining of the archenteron. The primary mesoblast divides bilaterally, i. e. in the median plane of the embryo, shortly after the forty-four-cell stage. The two mesoblasts retain a slight connection with the exterior, and at the ninety-cell stage have each divided transversely, the peripheral and posterior pair of cells are the *smaller*, and retain a slight connection with the exterior. The next division occurs in the anterior pair. The cells of the mesoderm continue to multiply until there are formed upon either side of the median line, extending forward from the posterior lip of the blastopore, two lateral bands of mesodermal elements. These bands are shown in longitudinal section in Figures 48, 49, and 50 (Plate VII.); in transverse section, in Figures 45 and 46. In Figure 48 the band consists of five cells, the posterior one of which in this stage is the largest. The band is somewhat curved, so that the anterior ends diverge from the more closely approximated posterior cells. In Figure 50 the lateral band contains six cells, the two at the posterior end being in a mitotic state. The position of their spindles is significant of the manner in which the bands have arisen, viz. by proliferation anteriorly from the posterior cell and its products. The "pole cell" as such is not sharply distinguished from the rest of the band by its size, as it is in Umbrella and Nereis. The position of the nuclei of two of the cells is suggestive of a division in a plane coinciding with the axis of the band. I have however never found a spindle in a plane perpendicular to that axis, though spindles parallel with the axis of the band are frequently found.

I have seen no evidence whatever that any of the cells of these mesodermal bands are derived from any other source than the primitive mesoblast, $d^{7.2}$. It is of course impossible to prove that none of the cells can have come from the external layers, either by migration inward, or by the division of a superficial cell in a plane parallel to the surface; but in the absence of any evidence that this does take place, and with such proof as Figure 50 (Plate VII.) gives, it seems not unreasonable to hold that the entire mesoderm is derived from the one cell, $d^{7.2}$. A comparison of the origin and development of the mesoderm in Nereis and Limax shows a precisely identical origin in the two forms. In Nereis, however, the mesoderm shares in the generally much more accelerated development, so that, although it appears at about the same cell stage in both forms, the relative number of mesoderm cells in Nereis in the later stages is much greater than in a corresponding stage of Limax. The accelerated division of the mesodermal quadrant (*D*) in the cleavages of the different quartets, as noted by Wilson and shown in the table of the cleavage of Nereis, may be a manifestation of this same accelerating force. I have not been able to find any trace of such a differentiation in the cleavage of the quadrants in Limax, where there are no early appearing larval organs and little acceleration in the development of the mesoderm. On the other hand, Lillie ('93) has been able to establish in Unio the same tendency of the quadrant *D* to precede in division; but in Unio again there is a very early development of larval organs. In Umbrella this tendency is not so marked, and here definite protoblasts are not distinguishable as early as they are in Nereis.

The later history of the mesoderm will be discussed in connection with the subject of gastrulation and the fate of the blastopore. There is never developed within these mesoblast bands, at any period of their history, a lumen, either such as Erlanger has described for Bythinia ('92) and for Capulus ('92$^{a}$), or of any other kind. The bands later lose their distinctness and break up into loose mesenchyma in which it is no longer possible to distinguish pole cells. The mesenchyma cells make their way between the ectoderm and entoderm layers, and by their multiplication and accumulation in different regions exercise a profound influence upon the form of the embryo. The obliteration of the mesoblast bands by this process renders the determination of the relation of the axes of these bands to the axes of the adult very difficult.

Inasmuch as both Erlanger ('91) and Heymons ('93) have recently given very full and satisfactory reviews of the conflicting literature on the origin of the middle germ layer in the Mollusca, it hardly seems necessary for me to go over the same ground. It will suffice in passing to call attention to the identity of my results, as to the origin of this layer in Limax, with those of Heymons ('93) on Umbrella, Lillie ('93) on Unio, Conklin ('91, '92) on Crepidula, Blochmann ('81) on Neritina, and Rabl ('79) on Planorbis, making allowance of course for possible differences in the case of Planorbis due to reversed cleavage. It seems very probable that the mesoderm may have a similar origin, i. e. from $d^{7.2}$, in the Pteropods (Fol '75 and Knipowitsch '91), in Aplysia (Blochmann '83), and in Fulgur (McMurrich '86).

## E. Theoretical Considerations.

The question as to the relation existing between the method of formation of the mesoderm described by Erlanger for Paludina and Bythinia, and the type presented in Umbrella, can find its satisfactory answer only in an examination of these first named forms from the cytogenetic standpoint. As the matter stands now, we are compelled to deny the morphological significance of the precise method of the origin of the middle layer, if we maintain its homology even within the group of the Mollusca.

The method of origin of the mesoderm in Cyclas, as well as the cleavage according to Stauffacher's description ('93), presents the material for an interesting comparison with that of its near ally, Unio. In the latter case the cleavage is spiral (Lillie '93), and the mesoderm (adult) comes, as in other cases of spiral cleavage, from $d^{7 \cdot 2}$. In Cyclas, on the other hand, is found a unique type of cleavage, mesenchyma appearing early, possibly at the seventh generation; but the "mesoderm," as distinguished from the mesenchyma cells, appears much later, and is not separated from the entoderm *before* its bilateral division. Such a case as this shakes one's faith in homologies based on forms of cleavage or cell lineage. Indeed, it seems impossible in the face of these conflicting results to assign to these phases of embryonic development any definite phyllogenetic significance. On the other hand, the identity of the cleavage processes among certain of the Mollusca (Umbrella, Unio, Crepidula, Neritina, and Limax), and the similarity of cleavage in these to that of an entirely different group of animals, viz. the Annelids, are phenomena not easily banished from the thought. They must have some significance, some common cause. To my mind the appeal to simple mechanical principles as an explanation of the phenomenon which, broadly speaking, we call the spiral, or alternating, type of cleavage, affords little satisfaction. If the principle of "the resumption of the spherical form," or that of "minimal surfaces of contact," prevails in one egg, why should it not in all eggs? We find the spiral type occurring in eggs with no, with little, or with much yolk, and the yolk, when present, variously distributed in the blastomeres; yet the spirals occur with absolute certainty and in a definite manner. Other eggs, presenting apparently the same mechanical conditions, cleave in accordance with an entirely different system, radial or bilateral, in both of which adaptations to mutual pressure may occur without a distinct spiral.

We can find a satisfactory explanation of the bilateral type of cleavage. It is simply an accelerated victory of a force which sooner or later dominates every developing egg of the Bilateria. Thus it is that the spiral type itself gives way to the bilateral, as Wilson has so well shown in Nereis.

It must be evident to all that the spiral type is very prevalent among the Trochozoa, i. e. among forms in which a free-swimming larva is early developed.

Thus, in Nereis at the thirty-eight-cell stage, not only are the germ layers completely differentiated, but most of the individual blastomeres are set apart as protoblasts from which definite organs or parts of the adult body are soon to arise. This occurs about five hours after fertilization, and at ten to eleven hours after that event the larva begins to rotate. Here we have a complete histological differentiation, while as yet only a comparatively small number of cells are present. Whether or not there exists any causal nexus between precocious development and the spiral type of cleavage, is a question upon which experimental embryology may be destined to throw some light; as yet experimentation has been confined to eggs having the radial or bilateral form of cleavage.

The three forms of cleavage, radial, spiral, and bilateral, are undoubtedly connected. Wilson ('93, p. 600) has suggested that the spiral type is a modification of the radial, and owes its peculiarities to mechanical conditions. I would also suggest that spiral and *bilateral* types are very intimately connected. The spirally cleaving egg is essentially bilateral from the time that the first cleavage plane appears, and an inspection of the tables of the cleavage of Nereis, Umbrella, and Limax shows that the embryo becomes predominantly bilateral as the spiral cleavage fades out. In Nereis the transition from the spiral to the bilateral period is abrupt; in Umbrella and Limax the two periods overlap during several generations. The cleavages which succeed those of the spiral type are meridional and equatorial, and I believe are to be referred to the bilateral rather than the radial type; indeed, in some cases, as in the division of 5.3 and 7.1 in Umbrella, the division approaches very closely the typical bilateral cleavage of the tunicate egg, i. e. is symmetrical with reference to the median plane of the embryo. Wilson ('92, p. 391) has referred the meridional cleavage of 5.3 to the *radial* type. In Nereis this quartet divides before the mesoderm appears; in Umbrella and Limax after it appears. When, however, in Nereis the quartet 7.15 divides equatorially *after* the mesoderm is formed, Wilson refers this division to the bilateral type. It seems to me that all these equatorial and meridional cleavages succeeding the spiral divisions both before and after the mesoblast appears must be referred to the bilateral period of the embryo and to the bilateral type of cleavage.

The precise agreement of Umbrella, Nereis, and Limax in these first bilateral cleavages is evidently something more than mere accident. The meridional character of the division in two of the cases (Limax and Nereis) suggests the possibility of similar mechanical conditions. But if all the conditions in the two cases are compared more closely, it becomes clear that there are important differences. The cleavage in question takes place in Nereis at the twenty-nine-cell stage, in Limax at the forty-four, and a comparison of Figure 39 or Figure 41 (Plate

VI.) with Wilson's Plate XV. Fig. 23 shows at once the great difference in the shape of the egg, and the mechanical environment of the cells under consideration. The evidence in this case, therefore, seems to point to some other force than that of mechanical condition as the determining cause of this remarkable agreement.

The intimate association of the spiral and bilateral types of cleavage, and also the prevalence of spiral cleavage in those animals possessing precociously developed larval forms, in which bilateral symmetry and histological differentiation are early impressed upon the cleaving ovum, suggest that the cause of spiral cleavage does not lie entirely in the external mechanical environment of the cells, but is, in part at least, to be referred to the same "morphogenic force" which produces the bilateral symmetry of the embryo and the adult. That the ultimate fate of cells exercises a profound influence upon their cleavage is well shown in the precocious cleavage of the mesoderm quadrant in Nereis and Unio, and of the teloblasts of the larval excretory organs in Umbrella. It may be that in like manner spiral cleavage itself is but a manifestation of precocious development of the organism as a whole.

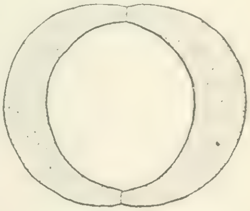
It is also difficult to explain the *alternation* of spirals by the mechanical conditions attending their formation. A glance at the tables of cleavage which I have given will quickly suggest that, although we have the same spiral in a given division of any generation in *all the eggs* having spiral cleavage, the conditions under which the spiral is formed in the eggs of different animals are by no means identical. The chronological sequence of the division of quartets in different eggs is not the same; neither is the distribution of the yolk, either in quantity or quality. The spirals however are always identical wherever they occur. These external mechanical conditions have doubtless a profound influence, but are they the only or the prevailing ones? If we predicate this, we must maintain that the resultants of these variously combined mechanical influences are identical in all cases of identical spirals. Be the *cause of the spiral* what it may, the internal conditions of nuclear division seem to be correlated with the *alternation* in direction in successive generations. In an unimpeded field of action, the division and subsequent equal migration of the two daughter centrosomes would necessarily produce a series of cell divisions at right angles to one another. This element is doubtless one of the factors in that field of complex activities, the cleaving ovum.

## F. The Cleavage Cavity.

### 1. *In Limax.*

After the blastomeres have reached the widely divergent state seen in Plate I. Fig. 14, they begin to flatten against each other, gradually losing their individual spherical contour and assuming a hemispherical shape. This process occupied, in a case recorded, about an hour, and was comparatively more rapid in the latter part. It results in the approximate restoration of the egg to the form of a single sphere. The superficial region of contact of the two cells appears in the living egg as a somewhat irregular line in the now almost obliterated furrow. Very soon after this process is completed there appear along this line lenticular or irregular spaces, devoid of the granular structure of the protoplasm, and apparently filled with a clear fluid. Deeper focusing reveals the fact that the centre of the apposed faces of the blastomeres is occupied by a slight cavity, wedge-shaped toward the vegetative pole, and broader and rounded toward the animal pole. This cavity gradually increases in size, the minor lenticular spaces increase also, and contiguous ones may be seen to coalesce. Finally, as the central cavity increases more and more, and approaches the periphery of the facet of contact, the lenticular spaces themselves disappear, probably contributing their contents to the encroaching central cavity. The latter now presents the form of a broadly lenticular clear space extending from the animal to the vegetative pole of the egg, and symmetrically developed with reference to these poles. The two cells are thus almost completely separated from each other by the fluid filling the cavity, as will be seen in the accompanying Figure E, giving an optical section in the plane of the equator of a two-cell stage of Limax agrestis, showing a cleavage cavity. They remain in intimate connection, however, at the peripheral margin, but this margin of union is in some cases reduced to a very thin layer of protoplasm. There is apparently no difference in the extent of the union at the two poles. The growth of the cavity results in an appreciable increase in the volume of the egg, and its contour, as well as that of the cavity itself, is suggestive of the high state of tension existing in the egg as a result of this increase in volume. In extreme cases, as in Plate V. Fig. 34, and in Figure E, the

FIGURE E.



cavity may attain a volume equivalent to one half or two thirds that of the undivided ovum. Throughout its whole history, from its inception to its culmination, both in the living egg and in preserved material, the cavity is always sharply marked off from the protoplasm of both cells. This is true, no matter what may be the point of view from which the egg is observed. Of course the boundaries of the cavity are indistinct where they lie oblique to the optical axis of the microscope, but there is always one focal plane at which the limiting "membrane" of the bounding cells sharply and distinctly separates the protoplasm from the fluid contents of the cavity, and moreover there is no trace whatever of any shading off of the protoplasm toward the cavity such as Stauffacher ('93) describes in Cyclas. We are therefore compelled to conclude that the cavity is distinctly intercellular.

The maximum development of the cavity is followed by a forcible expulsion of its contents. This takes place suddenly, and the elimination of the fluid may be total, or only partial. After a total elimination the egg resumes its original size, and tends to take again the spherical form. In case of a partial expulsion the cavity retains its polar diameter, but the antero-posterior diameter is reduced (Plate I. Figs. 5, 6). In the egg represented in Figure E, the spindles leading to the third generation were present when the cavity of the two-cell stage had reached its maximum. It often happens that two or even more expulsions of the liquid contents of the cavity occur between the two- and the four-cell stages. In the series represented in Plate I. Figs. 1–7, drawn from the same egg kept under continuous observation, the two blastomeres had attained the maximum divergent or rounded condition at 11.30 A. M. At 12.35 P. M. they had reached the flattened or coalescent condition (Figs. 1, 2), and at 12.45 P. M. the central cavity had appeared (Fig. 2). This increased in size (Figs. 3–5), reaching a maximum at 1.30 P. M., when a partial expulsion occurred (Fig. 6). After this expulsion the nuclei could no longer be seen distinctly in the living egg. The cavity again increased in volume (Figs. 6, 7), and at 2.02 P. M. a second and total elimination took place coincidently with the division into four cells; this was accomplished, i. e. the furrows had reached the vegetative pole, at 2.05 P. M.

It is not always possible to determine the point at which the fluid contents are ejected. When a sudden reduction in the size of the cavity is noticed, there is sometimes visible in the albumen adjacent to the cleavage furrow a small sphere of transparent matter differing in its refractive index from the surrounding albumen into which it very quickly merges. When, however, the reduction in the size of the cavity is gradually accomplished, occupying in one instance recorded about five minutes, no trace of the extruded liquid is visible. I have observed in the two-cell stage the expulsion of the liquid at both animal and vegetative poles, but never at both poles of an egg at the same time. Warneck ('50) and Fol ('80) both state that the contents of the cavity are expelled at the vegetative pole. This is certainly by no means constant, and I am inclined to believe that in a majority of cases, especially in the later stages, the elimination takes place at the animal pole of the egg.

This ephemeral cleavage cavity is not confined in Limax to the two-cell stage, but is equally prominent in the stages immediately following. The passage of the egg from the two- to the four-cell stage may be accompanied by an incomplete elimination of the contents, for I have often observed cases where a small cavity persists throughout the progress of this cleavage.

Figures 8–13 (Plate I.) show the history of the cleavage cavity in a different egg from the one observed during the two- to four-cell stage. At 3.15 P. M. there was no trace of any cleavage cavity, and the second cleavage furrow had almost reached the vegetative pole. Half an hour later the characteristic four-cell condition had been reached (Fig. 8), and in ten minutes more a cleavage cavity of considerable volume was developed in the vertical axis of the egg. This continued to increase in size until 4.45 P. M. (Figs. 9–11), when a total expulsion of the contents occurred, occupying not more than thirty seconds (Fig. 12). The nuclei at this period were at the amphiaster stage. Within fifteen minutes a new cavity had appeared in the now elongated vertical axis of the egg. This cavity was at first very narrow and extended almost from pole to pole. It increased slowly in volume, but was not wholly obliterated at the division into eight cells, which occurred at 5.38–5.45 P. M. (Fig. 13). It is not at all unusual to see the total elimination of the contents of the cavity at the division into eight cells, but the occurrence is not constant. The configuration of the cavity of the four-cell stage as viewed from the animal pole is shown in Plate II. Fig. 17. It is almost rhomboidal in outline; the angles lie at the cleavage planes, and the sides are curved with the convexity next the cavity. It is probable that a partial expulsion, or perhaps a total one, has already occurred, for the cavity was not very large and the nuclei were in the early phase of metakinesis when the egg was killed. When the cavity is at its maximum it assumes very nearly a spherical shape, i. e. the bounding cells are concave toward the cavity, and they present more nearly the character of a wall of uniform thickness (Fig. E, p. 81). No case has come under my observation where a nucleus projects into the cavity, as Stauffacher ('93) figures it in his Tafel XIII. Fig. 19 *a*.

An interesting condition is found in Plate II. Fig. 16, in which the second cleavage furrow is almost completed. The cavity appears to have been divided into two parts by the recent cleavage furrow, and now consists of two large lenticular spaces, one between the cells *A* and *D*, the other between *B* and *C*, i. e. both spaces are in the first cleavage furrow. The first appears to lie mainly in the cell *A*, but this is due to the fact that *A* lies slightly above and upon *D*. The cavity between *B* and *C* has several secondary contributory spaces lying superficially to it in the furrow at the animal pole.

The cavity of the eight-cell and later stages differs from that of the two-cell stage in that it is situated nearer the animal than the vegetative pole of the egg. This is correlated with the size of the two quartets of the fourth generation, Plate III. Figs. 20 and 21, and may be the occasion of the frequent escape of the fluid contents at the animal pole.

It is not necessary to follow in detail the phenomena which attend the further history of the cleavage cavity, as it would be in the main a repetition of the description of that of the earlier stages. I shall merely call attention to certain features of the cavity which are of especial interest.

An examination of a large number of eggs in the living state, as well as killed and hardened material studied both *in toto* and in sections, has led me to the conclusion that this ephemeral and recurrent phase of the cleavage cavity or blastocœl continues until a late stage, even to the period of gastrulation. That its appearance is not due to a pathological condition of the embryo is shown by the prevalence of the same phenomenon in eggs collected in the natural environment of the slug, as well as by the development of normal embryos from vacuolated eggs. It may be that confinement conduces to the presence of the ephemeral cavity in its various forms, but I have no direct evidence that such is the case.

Eggs presenting the maximum development of the cleavage cavity in the later stages are with great difficulty freed intact from their envelopes and require especial care in the subsequent treatment with reagents. On Plate V. (Figs. 33 and 34) is figured an egg of twenty-four cells with a well developed cleavage cavity. The nuclei are all in a quiescent state, and the cells form a wall of such uniform thickness that it was only after repeated trials that the vegetative pole of the egg could be determined. The cavity is so large that the facets of contact are very narrow, and the individual cells are in optical section somewhat lozenge-shaped. The cell $a^{6.2}$ (Fig. 34) presents a curious bud-like process extending into the central cavity, and the superficial extent of the cell is somewhat less than that of the other members of the same quartet. This process suggests the mesenchyma cells which Stauffacher ('93) figures in his Tafel XIV. Figg. 25 *a* and 25 *c*, but in this projection there is not the least trace of any nuclear structure, and it is probably a mere amœboid outgrowth of no permanent significance.

A comparison of the computed volumes of the whole egg, of its cavity, and of the protoplasmic portion, with the volume of another egg (Plate IV. Fig. 27) of the same stage but having no cavity, brings out the following results. The whole egg has 429 units of volume, of which 188 represent that of the cavity, 241 that of the blastula wall, while the twenty-four-cell stage of average size (Fig. 27) has a volume of only 126 units. These figures assume the perfect sphericity of the objects measured, and are therefore only approximately correct; still they show that the first egg, though a large one, is within the limits of variation in size, and that the cavity is larger than the average egg, but not so voluminous as the substance of the egg which contains it. It is also suggested, in view of the large size of the egg, that the cavity has not been developed to any great extent at the expense of the volume of the protoplasm of the egg. There can be no question that this egg presents the condition of a typical "blastula" with a typical "cleavage cavity" or blastocœl. Indeed, Rabl could not have found for Haeckel and his Gastræa Theory a better illustration among mollusks of the "morula" and "blastula" stages than these two twenty-four-cell stages (Plate IV. Fig. 27 and Plate V. Fig. 34); for the first contains no cavity whatever, and the latter has its cells arranged in a single layer about a cavity. On the other hand, if we accept the limitation set upon our usage of the term cleavage cavity by Stauffacher in his recent paper ('93), we shall be compelled, in view of the fact that the cavity is sooner or later entirely eliminated, to call this beautiful example of a cleavage cavity simply "ein heller Raum."

It is difficult to establish any regularity or uniformity in the sequence of the phases of the cavity in these later stages of cleavage. When we examine other eggs in the twenty-four-cell stage we meet with different and by no means constant conditions. The twenty-four-cell stage represented in Plate IV. Fig. 31, shows no trace whatever of a cavity; while Figure 28, also a twenty-four-cell stage, shows at the animal pole a number of lacunæ or intercellular vacuoles between the cells of the apical quartet, $a^{5.4}$ — $d^{5.4}$ and their neighbors. An especially large vacuole is formed immediately at the animal pole.

Inasmuch as the vacuolation of the animal half of the egg is an important and very prevalent occurrence in the later stages in the cleavage of Limax it deserves a detailed description. In surface view these cavities are seen to be arranged in general along the line of the cell boundaries, which they obscure to such an extent that the superficial margins of the facets of contact are detected only by careful focusing upon the immediate surface of the egg properly illuminated. As soon as the plane of the focus is lowered toward the level of the nuclei, the boundaries are at once lost and nothing but a clear space can be found. The protoplasm peripheral to the cavity is therefore comparatively thin, and does not present the granular structure of the deeper lying regions. The cavities in many cases extend laterally upon either side some distance from the superficial line of contact of the two cells, and sometimes, as in the cell $c^{5.3}$, Figure 28, they even lie between the nucleus and the external surface of the cell. In all cases it is possible to detect a sharp and definite boundary to these cavities, when the egg is so oriented as to bring the margin of the cavity into the proper relation to the optical axis of the microscope. These boundaries have the same appearance in whole preparations and in sections that cell boundaries have, and indeed I believe that they are cell "membranes," and that the cavities are strictly *intercellular*. That part of the facet of contact lying peripherad to the cavity is not continuous through the cavity with the part centrad (Plate III. Figs. 24, 25), but is in direct continuity with the wall of the cavity. This seems to me to be indisputable proof that these vacuoles are intercellular structures, just as the lenticular spaces and central cavity of the earlier stages of cleavage and the large cavity of the twenty-four-cell stage are. The question as to whether these should be called the cleavage cavity will be discussed later.

The appearance of these cavities in section is shown in Figures 24 and 25 (Plate III.). The egg here represented is a very small one, only 80 $\mu$ in diameter, and is shown *in toto* in Figure 23. It has just been derived from the sixteen-cell stage by the division of the quartets 5.1 and 5.2. Traces of this division can still be seen in the derived quartets 6.1, 6.2, and 6.3, 6.4. The sections were cut obliquely to the vertical axis, and so directed as to cut longitudinally the remnants of the spindles in one of the quadrants of the quartets 6.3 and 6.4. There is a medium-sized central cavity, which, owing to the recent division and consequent rounded condition of the cells concerned, lies nearer the vegetative pole.

The section shown in Figure 25 cuts the cells of the animal pole obliquely, and thus exaggerates their relative size somewhat. In addition to the central cavity, there are a number of smaller cavities between the cells of the animal pole. Their relation to the cell boundaries can in every case be readily determined in the sections. The larger cavity *x* of Figure 24 is between two cells whose facet of contact lies parallel to the plane of the section ; the cavity therefore appears to traverse a cell, though in reality it does not. In the figure it is in direct continuity with cavities which are readily seen to be intercellular. These latter cavities appear lenticular in cross section, but they are themselves elongated as the cavity *x* is. There are, in addition to the intercellular cavities just described, two others (*vac.*, Figs. 24 and 25), which seem to be *intracellular*). They are both near the central cavity, though not in direct contact with the cell membrane in any direction. They are both approximately *spherical* in form, and neither has the sharp and definite outline separating it from the protoplasm of the cell that the intercellular spaces just described have. Their form, position, and limits thus indicate their intracellular nature. They probably are merely intracellular vacuoles. Their position is suggestive of their fate. They lie very near the central cavity, and it may be that their contents ultimately find their way into it by osmosis, or less probably by rupture of the "cell wall."

The fate of the fluid eliminated from the lenticular spaces of the earlier stages, and from the intercellular spaces of the later stages, is a difficult matter to determine. Direct observation gives negative results, for although these cavities in the early stages can be seen to develop and disappear, it is impossible to say what becomes of their contents. I have never seen any evidence of the extrusion of their contents from the egg, but this might escape observation, for the cavities are small and their contents are transparent, and it is often difficult to determine the point at which the contents even of the large cavity are expelled.

There are, however, some facts which lend support to the view that these lenticular spaces of the early stages, and perhaps also the intercellular spaces of the later stages, contribute directly to the increase of the volume of the central cavity. The nuclear conditions of Figures 23–25 (Plate III.) show beyond question that this twenty-four-cell stage is younger than that of Plate V. Fig. 34, where the larger cleavage cavity is shown. It seems reasonable to derive the conditions of the older stage from those of the younger. The main difference between the two stages lies in the increased size of the cleavage cavity and the absence of the secondary intercellular cavities in the older egg. It seems probable that, as the central cavity grows in volume and the facets of contact diminish in size, the central cavity extends to these secondary cavities and fuses with them, and that thus all portions of the surfaces of the cell, except its exterior one, may contribute secretions to the central cavity. The immediate proximity of several of these secondary cavities to the central cavity in Figures 24 and 25 (Plate III.) suggests that the former may even actually move toward the central cavity. The direction of the motion is merely a question of the direction of least resistance; it is difficult to explain the development of such a large cavity as that of Figure 34 (Plate V.) and the subsequent forcible expulsion of its contents, and the immediate restoration of the egg to a solid spherical mass, without admitting the existence of a considerable force, tending to preserve intact the contour of the egg, and resisting the increasing tension brought about by the enlargement of the central cavity. If the contents of these smaller cavities are eliminated to the exterior, why should not those of the large cavity, whose tension must be proportionally greater, be eliminated at the same time? There is a point, however, beyond which the increase in the size of the central cavity cannot go. The outer wall yields to the pressure, and the imprisoned fluid escapes. I have found no trace of an egg membrane, such as Gegenbaur ('52) has described for the egg of Limax agrestis: "Es besitzt eine Zellmembran, die besonders durch längere Einwirkung von Wasser deutlich erkennbar wird." There is no evidence that there is anything more than the ordinary clear stratum of protoplasm at the exterior of the egg. In this my observations are in accord with those of Dr. Mark upon Limax campestris ('81). None of these secondary cavities or lenticular spaces were observed in the eggs which have the maximum central cavity, neither have they been seen at the time of the expulsion of the contents of the cavity, even when that takes place gradually. They are associated with the growth rather than with the disappearance of the central cavity. In view of these facts, it seems to me that we are justified in concluding that, in some cases at least, the lenticular and the secondary intercellular spaces contribute to the increase of a central cavity.

As has been stated already, these secondary intercellular spaces often form at the animal pole of the egg, while not a trace of them can be found at the vegetative pole. They may present the appearance of an anastomosing network of irregular vessel-like structures between the cells of that pole of the egg, as in Plate VI. Fig. 39. It hardly seems possible that a histological differentiation can have already taken place between the two poles of the egg whereby the cells of the animal pole are set apart to perform an excretory function. This is rendered still more doubtful by the frequent occurrence of eggs in which these secondary intercellular spaces have reached an enormous development at both poles, in fact throughout the whole egg. This condition may occur as early as the twenty-four-cell stage. In such eggs there is never any distinct central cavity present; it becomes difficult in such cases to locate cell boundaries and the relation of nuclei to them. In Plate III. Fig. 26, is shown a transverse section of such an egg containing more than one hundred cells. In stainability and nuclear conditions this is not essentially different from other eggs; several cells of this egg are in a mitotic state; I therefore believe such eggs to be normal. As can be seen in the figure, the three germ layers are present, and the vacuolation surrounds the cells of all three layers indifferently. There is no central cavity, and the three layers retain their connection with one another. Indeed, this condition is very suggestive of that found in the gastrula at the time when the head-vesicle is beginning to develop and the entodermal cells are sending out long processes into the fluid-filled space toward the cells of the other layers. It seems therefore no misuse of terms to designate the intercellular spaces in both cases as the primary body cavity, which throughout the period of segmentation is also the *cleavage cavity*. The condition represented in the figure is ephemeral and the extrusion of the liquid contents may take place without the formation of a spherical central cavity. The spaces seem to be thoroughly connected with one another and when some point on the periphery of the egg yields to the pressure, the fluid is probably in large part eliminated.

The occurrence of a single distinct central cavity is shown in Figure 47, a section of an embryo of eighty cells, and likewise in Figures 48 and 49 (Plate VII.), where the embryo has assumed the flattened shape characteristic of the stage preceding gastrulation. In this egg the cavity is small and lies between the ectoderm, the entoderm, and the bilaterally placed mesoderm bands. There is no trace of any cavity in the mesoderm. In Figure 54 the cavity occupies a position at the posterior end of the blastopore, and, as in the preceding stage, lies next to the ectoderm on the dorsal side of the embryo. I have found many embryos, not figured, which have this definitely limited central cavity. In no case, however, has it attained the size of the cavity in the twenty-four-cell stage shown in Plate V. Fig. 34. On the other hand, a large part of the embryos examined have either the intercellular vacuolation or no trace of any cavity whatever.

What is the morphological and what the physiological significance of the phenomena with which we have been dealing? Are these cavities all simply different phases of one and the same thing, — an ephemeral recurrent cleavage cavity, — or do they differ among themselves, and are they to be considered as different from the cleavage cavity? Do they bear any relation to the conditions under which the egg develops? My work has left no doubt in my own mind that they all belong to the same category, — modifications of the cleavage cavity, — and that they are perhaps intimately connected with the conditions in which the embryo develops. I shall refer to these points again after reviewing the literature of the subject.

The question might well be raised as to whether the term cleavage cavity should be used to designate the phenomena which we have discussed. If we are to apply this term to that continuous, persistent cavity into which the invagination resulting in gastrulation takes place, and that only, then we assign to the term an unduly limited morphological significance, suggested by the Gastræa Theory of Haeckel. Then this ephemeral cavity in Limax is not a cleavage cavity, and we must coin some new term to distinguish it, such, for example, as excretory cavity. If, on the other hand, we recognize the physiological importance of this and other cleavage cavities, while not denying their morphological significance, and bear in mind also the constant intercellular nature of the phenomena in question, it is in my opinion perfectly legitimate to designate by the term cleavage cavity any and all of the protean forms which the intercellular space assumes in Limax. The matter of terms is, however, a minor point, the unity of the phenomena is the important one.

There remains one more question of interest. Is there any relation between the stages of cleavage and the recurrence of the cavity? Warneck, in 1850, stated that the cavity reaches its greatest development contemporarily with the "Maximum der Entwickelung der Kerne." My own observations do not show that this is always the case. In Figure E, the two cells enclosing the large cavity contain, not nuclei with distinct membranes, but spindles. There is a mechanical cause for the elimination of the contents of the cavity at the period when the cells assume a rounded condition at the close of cleavage. The facets of contact are then much reduced, and the resistance at the periphery of the egg to the expulsion of the fluid is more readily overcome. It may also be that the periods of great activity in the cells at the time of division are periods at which the osmotic processes reach a maximum, and thus the cleavage cavity may grow rapidly at this time. My observations on living eggs show that the period immediately preceding division is that of the most rapid growth of the cavity. It is not an uncommon thing to find in the later stages neighboring cells in a mitotic state enclosing a lenticular space between them. These two causes may result in producing in some cases, during the early stages of cleavage, an apparent rhythm between the nuclear conditions and the periods of expulsion. There is, however, much variation in these early stages, and it is impossible to establish in them any such constant correlation as Warneck has indicated.

## 2. *Literature.*

### AMPHINEURA.

No mention is made of any cleavage cavity in the development of Dondersia, as described by Pruvot ('90). Kowalevsky ('83) does not discuss the subject in Chiton, but Metcalf ('93) describes the cleavage cavity as already formed at the four-cell stage. No statement is made about its subsequent disappearance.

### LAMELLIBRANCHIATA.

#### I. *Marine Forms.*

Lovén ('48) does not figure a segmentation cavity in either Modiolaria or Cardium. Barrois ('79) makes no reference to any segmentation cavity in Mytilus, though his Plate XII. Fig. 16, if it represents a *section*, shows such a cavity. He distinctly states that the segmentation produces a body considerably larger than the original ovum. He also notes in the two-cell stage the appearance, in one instance, of lenticular refractive bodies apparently identical with those figured by Bobretsky as found in Nassa mutabilis. These bodies are adjacent to the furrow separating the micromere and macromere of the two-cell stage, and may be due to a highly refractive secretion accumulated in these regions.

Brooks ('80$^a$) describes in Ostrea Virginiana a transparent cavity separating the ectoderm from the macromere *in dead eggs* at a stage when the macromere is almost covered by the very large number of ectoderm cells present. He does not regard this space as normal, since the macromere seems in living eggs to be in contact with the outer layer, and there is no indication of a segmentation cavity. It is only concerning a later stage, when the macromere has divided into a number of entoderm cells, and the embryo is much flattened in the dorso-ventral direction, that he says a distinct "segmentation cavity, or more properly a body cavity, is now clearly visible" between the ectoderm and the entoderm. Horst ('82) says, "It is not possible to demonstrate the existence of a true cleavage cavity in the oyster."

Hatschek ('80) finds that one of the peculiarities of the development of Teredo is "der gänzliche Mangel der Furchungshöhle."

## II. *Fresh-Water Forms.*

Forel ('68, p. 14) called attention to the fact that the "yolk" in Unio later becomes clear and transparent, but he failed to interpret this appearance as a cavity. It remained for Flemming ('75) to show in Anodonta the presence of a cleavage cavity as early as the two-cell stage, to establish its recurrent character, and to assert its equivalency to the cleavage cavity of the later stages. He notes its formation as a lens-shaped cavity between the macromere and micromere of the two-cell stage; its disappearance with approaching cleavage; its reappearance in the four-cell stage, and its subsequent disappearance before the next cleavage begins. He also notes its relatively large volume in a stage when there are from six to ten micromeres, but he does not describe any further obliterations of the cavity. The fact that the earlier cavities are obliterated does not raise the question with him as to whether they should be regarded as cleavage cavities or not.

Rabl ('76) has observed a similar phenomenon in Unio pictorum. He describes the cavity as a transparent protoplasmic layer with few yolk granules between the cells of the two-cell stage. He contends, however, that it is not the beginning of the cleavage cavity, as Flemming had maintained, and calls attention to the fact that similar regions, free from granular structures, between two or more cleavage spheres, are met with in the embryos of other animals, as, for example, in many Gasteropods, where the cleavage cavity appears later than it does in Unio. At the four-cell stage, however, he recognizes "die erste Anlage der Furchungshöhle," but does not speak of any reduction or disappearance of this cavity in later stages, though some of his figures suggest it.

Korschelt ('91) speaks of an expansion of the primitively narrow segmentation cavity of Dreissena, during which the embryo, which has reached the gastrula stage, assumes a roundish oval shape. No mention is made of the ephemeral or recurrent character of this primitive cavity. It is a matter of considerable interest to see that Dreissena, which is a "near ally of the common mussel," and is probably a recent migrant into a fresh-water environment, still retains the free-swimming larval stage characteristic of marine forms. It has acquired, however, the "primitive segmentation cavity" found in the fresh-water Lamellibranchs, but not definitely known to be present in the marine forms.

Lankester ('74) does not refer to the cleavage cavity of Pisidium, nor does he figure it except in comparatively late stages of development.

Von Jhering ('76) speaks of the three or four small cells in Cyclas, whose progeny grow around the solid mass of the two large cells, and of the later appearance of a cavity in the centre of this mass. Ziegler ('85) finds a cavity in the thirteen-cell stage of Cyclas, but indicates no cavity in the two earlier stages that he figures.

The latest, and by far the most important, contribution to our knowledge of the cleavage cavity is that of Stauffacher ('93) upon Cyclas cornea. The formation of a "true" cleavage cavity takes place at the thirteen-cell stage by the gradual elevation of the cap of ectoderm cells from the macromere to which they had been closely applied, resulting in the development of a sharply defined space between the macromere and its derivatives. This cavity persists and increases in size until it ultimately becomes the relatively very large cavity of the blastula stage. In addition to this cavity, which he regards as persistent from the thirteen-cell stage on, Stauffacher finds in the two-cell stage a structure which he regards as similar to that observed by Flemming in Anodonta and by Rabl in Unio. He describes it as a disproportionately large space, entirely unstainable, *in* the smaller of the two spheres, exactly in the region where they are in contact. The cavity is filled with a fluid free from granules. The protoplasmic part of the cell, which forms the peripheral layer and contains the nucleus, merges very gradually into this fluid-filled space. On the side of the macromere this space is sharply and definitely limited. It seems from his description that this space is regarded by him as lying *in* the smaller cell, i. e. intracellular, though he does not distinctly designate it as such. The interpretation of this space and its later history are best given in his own words (*loc. cit.*, p. 211): "Es fällt bei Cyclas nicht schwer, den unumstosslichen Beweis zu erbringen dass der genannte helle Raum in der That nichts mit einer Furchungshöhle zu thun hat. Dieselbe körnerlose Partie nämlich, die wir auf dem zweizelligen Stadium antreffen, ist zwar auch auf dem dreizelligen Stadium noch vorhanden, aber schon bei der Bildung der vierten Furchungskugel wird sie bedeutend reduziert und verschwindet schliesslich ganz. Dagegen entstehen im weiteren Verlauf der Entwickelung zwischen der grossen Mutterzelle und ihren jeweiligen letzten Abstammungsprodukten neue solche Partien. Die eigentliche Furchungshöhle tritt bei Cyclas, wie wir sehen werden, erst in bedeutend höheren Furchungsstadien auf."

A cavity similar to that of the two-cell stage is figured for the four-, five-, six-, seven-, nine-, and twelve-cell stages, occurring always between the macromere and its most recent products. This cavity becomes successively smaller from the four- or five-cell stage until we reach the relatively small cavity of the twelve-cell stage. It is always sharply limited from the macromere, and often presents on the side next the most recent micromere, or its products, the gradual merging into the granular protoplasm noted in the two-cell stage. That is to say, here, as there, the inference is that the cavity may be regarded as an intracellular space. The fluid which fills this decreasing cavity he thinks is absorbed in large part by the macromere, and perhaps to a less extent by the micromeres, and that it does not pass out of the cavity through the egg membrane. After this fluid-filled space has disappeared from between the earlier formed micromeres, $m^1$, $m^2$, $m^3$, $m^4$, and the macromere, the micromeres in question apply themselves closely to the macromere in a way that suggests the fusion of micromeres with the macromere noted, as by Lovén ('49) in marine Lamellibranchs, and by Bobretsky ('77) in Nassa. With regard to the interesting phenomenon of fusion described by these authors, Stauffacher makes the following suggestion: "Es erscheint mir nicht unwahrscheinlich dass vielleicht in allen den Fällen, wo ein nachträgliches Abflachen der kleineren Zellen konstatiert wurde, auf günstigen Prepäraten auch der helle Raum zwischen den Furchungskugeln hätte nachgewiesen worden können, der durch sein Verschwindung das Anschmiegen der Mikromeren möglicherweise bedingt." "Der helle Raum" has, however, never been recorded by any investigator of these forms; furthermore, the fusion in some cases (and these are the most marked cases of fusion) consists in the reunion of the more richly protoplasmic part of the macromere with the more passive yolk-bearing portion, from which it had abstricted itself at the time of nuclear division.

Neither Bobretsky ('77) nor Brooks ('80) figures a nucleus in the "macromere" with which the micromere so completely fuses; and it seems hardly possible that in these cases the disappearance of a cavity can have anything at all to do with the phenomenon of fusion. There are moreover some objections to the view that in the two-cell stage the cavity lies *within* the cell, and to the inference that it is essentially of that nature in the later stages. Stauffacher himself does not emphasize, or even clearly present this view, though he repeatedly calls attention to the lack of a sharp differentiation of the cavity from the protoplasm of the most recent derivative or derivatives of the macromere. The fact that this gradual transition is shown toward *two* cells, as in his Taf. XII. Figg. 14 *a–g*, and Taf. XIII. Fig. 18 *b*, militates against the view that the cavity is intracellular. It may well be that the yolk-laden macromere, on account of its different stainability, is more sharply marked off from the cavity than the protoplasmic micromere; but is it not possible that the gradual transition of the granular protoplasm of the adjoining cell into the clear space of the cavity is in most, if not all, of the cases figured by Stauffacher due to oblique sections of the limiting membrane? His figures of the whole egg are made from reconstructions on glass plates, and in them the outlines of the cavities are not distinctly traced. In most cases he has not indicated the planes of the sections which he figures; these must therefore be inferred from the position of the nuclei. Such inferences, however, lead one irresistibly to the conclusion that the sections must meet the boundary of the cavity obliquely wherever its outline appears indistinct; e. g. Taf. XII. Figg. 14 *a–g;* Taf. XIII. Figg. 18 *a* and *b*. On the other hand, sections which appear to strike the cavity perpendicularly, as in Taf. XII. Figg. 15 *a* and *b*, 16 *a* and *b*, and 17 *a*, all show a much more distinctly marked separation of the protoplasm of the cells from the cavity, and in some cases this demarcation is as definite on the side of the most recent micromere as it is upon that of the macromere. In case this explanation should prove valid, we shall have in Cyclas, as in Limax, an intercellular cavity appearing at the two-cell stage, and recurring in the later stages of cleavage.

I cannot agree with Stauffacher's view that this primitive "heller Raum" has nothing whatever to do with the true cleavage cavity. It is not established even by the facts found by him in Cyclas; much less by a comparison with other forms presenting a similar phenomenon. His observations are confined to killed, preserved, and hardened material of very limited amount. He had in some cases not more than one series of sections of each cleavage stage; of the three-cell stage seven series, of the four-cell stage six series. He has not been able to examine the eggs in the living state, or in whole preparations. Thus he has been deprived of most valuable assistance in determining the origin, definite boundaries, successive phases, ultimate fate, and relationships of this "heller Raum," whose claim to the title of cleavage cavity he so summarily dismisses. The "unumstosslich Beweis" which he brings forward to support the view he advances is, that the "heller Raum" finally disappears entirely. But his figures and descriptions show that this clear area merely occupies a different position with reference to the first micromeres, not that it entirely disappears. Every stage that he figures, from the two- to the thirteen-cell stage, where, upon his interpretation, the true cleavage cavity first appears, contains a cavity. He brings forward no proof to show that these may not be continuous both with one another and with the cavity of the thirteen-cell stage, which is in his view the true cleavage cavity. It seems to me, then, that his own evidence does not conclusively sustain the view that this primitive cavity is not a true cleavage cavity, as he himself has defined it. Indeed, we should expect that in Cyclas, as in other fresh-water mollusks, there might be an entire elimination of the cavity at intervals, though he has not proved it. Even if we grant that in Cyclas the primitive cavity is eliminated, we have still the important point to consider whether or not such an elimination constitutes a valid ground for removing the "heller Raum" from the category of cleavage cavities. A comparison of the phenomena in Cyclas with those presented in such a form as Limax would seem to indicate that we are dealing here, as there, with an ephemeral recurrent cleavage cavity present at the very beginning of segmentation.

### SCAPHOPODA.

Kowalevsky ('83) finds a definite cavity appearing in Dentalium as early as the eight-cell stage. This gradually increases in size, forming quite a large cavity at the time of gastrulation.

### PROSOBRANCHIATA.

#### I. *Marine Forms.*

An examination of the literature of Prosobranch development shows an almost entire absence of references to a cleavage cavity. The few allusions that exist are concerned with the cavity that appears comparatively late in the period of cleavage.

Bobretsky ('77) finds a cleavage cavity in Nassa mutabilis at the thirty-six-cell stage. Although the alternation of the rounded with the flattened conditions of the cells in cleavage is quite prominent in Nassa, no cavity is noted as occurring between the fused cleavage spheres.

McMurrich ('86, p. 412) makes the following statement with regard to the segmentation cavity in Fulgur: "To one side of the blastoderm and below it a more or less distinct cavity is to be seen, containing granular matter. It is possible that this may represent the segmentation cavity, though it does not appear to be present in all cases." This is in a stage preceding the formation of the "sixth generation" of micromeres and the appearance of the mesoderm. Brooks ('78) figures at a late stage a cavity in Urosalpinx similar to that found by Bobretsky in a late stage of Nassa. Patten ('86) does not figure any segmentation cavity in Patella, but in the later stages, before gastrulation, a medium-sized central cavity is present. Conklin ('91) finds in Crepidula, "at an early period, a trace of a segmentation cavity, which, however, is soon obliterated."

### II. *Fresh-Water Forms.*

Blochmann ('81) does not discuss the subject of the cleavage cavity in Neritina, but it is evident from his figures that, if it is present at all in the earlier stages, it does not attain a great size. Neritina contains a large amount of yolk, and this may have some effect on the cleavage cavity. In the late stages a small cavity appears between the ectoderm and the macromeres.

No mention is made by Sarasin ('82) of a cleavage cavity in Bithynia until the close of the cleavage period. Sections of the early stages were not cut. Erlanger ('92) finds a large cavity present at the close of segmentation, i. e. before the formation of the mesoderm and when the blastomere contains, according to his estimate, at least sixty cells. In Paludina vivipara, Lankester ('76) finds in a late stage of cleavage "a central space or cleavage cavity." A cavity of considerable size is also figured by him as present at the time of gastrulation. On the other hand, neither Bütschli ('77) nor Blochmann ('83) succeeded in finding in this species any cavity in the cleavage stages examined by them, nor more than a mere slit-like cavity between the layers at the time of gastrulation. Erlanger ('91), however, finds a large cavity in the gastrula stage, and it is into this cavity that the mesodermal pockets described by him are evaginated. If Paludina has an ephemeral recurrent cavity similar to that of Limax, the apparently discordant observations of Lankester, Bütschli, and Blochmann would be easily harmonized.

I have myself watched the cleavage of the eggs of Amnicola limosa, and find that they present a typical recurrent cavity, precisely like that of the fresh-water pulmonates. The eggs of Amnicola are enclosed in capsules and are surrounded by a jelly-like albumen. They contain a small amount of yolk, and cleavage is not so unequal as it is in Neritina.

### OPISTHOBRANCHIATA.

There seems to be an entire absence of references to the presence of a cleavage cavity in the development of this group.

Heymons ('93) found in Umbrella no trace whatever of a cavity at any period up to the formation of the larval stage.

### PTEROPODA.

Fol ('75) says of the two-cell stage of the Pteropods, "Mais il ne se produit pas ici, comme chez le Lymnée et la Limace, ou comme chez les Geryonides, des vacuoles entre les cellules." Nor is a cleavage cavity described by him for the later stages. Knipowitsch ('91) mentions a "spaltförmige und nicht immer deutlich wahrnehmbare Furchungshöhle," into which the mesodermal cells migrate, as occurring at the end of cleavage in Clione.

### PULMONATA.

Warneck ('50, pp. 131–135, 166–170) discusses the recurrent cleavage cavity in Limax and Lymnæus. He describes its appearance soon after the two cells begin to flatten against each other; also its growth and subsequent disappearance when the second cleavage plane appears. A similar phenomenon occurs at each succeeding phase of cleavage till the blastula stage is reached. He expresses the opinion that this "heller Raum," as he calls it, is a receptacle for albumen, and describes the expulsion of its albumen-like contents into the surrounding albumen at the time of the disappearance of the cavity. He explains the phenomenon as due to the acceleration of end- and ex-osmosis, attendant upon the greater activity of the nutritive and excretory functions of the cells and the disappearance and reappearance of the nucleus during the successive phases of cleavage, and correlates this activity of the cells with the origin of the ovum from a glandular tissue. Ganin ('73) mentions the relatively small cavity in Lymnæus, and the larger cavity in Physa. In Helix, von Jhering ('75) finds a central cavity in the two-cell stage. The later stages of cleavage were not carefully followed by him, and no further mention of the cavity occurs in his work.

Fol ('80, pp. 115 and 116) says: "Pendant le travail du fractionnement, les sphérules prennent un aspect foncé et une forme arrondie. Les noyaux ne sont plus visibles et la cavité de fractionnement se perd dans l'obscurcissement de l'œuf. Pendant les temps de repos les noyaux reparaissent, les sphérules s'affaissent les unes sur les autres, la cavité de segmentation est de nouveau visible. Dans ces périodes de repos, la limite entre les sphérules apparaît comme une ligne d'épaisseur très appréciable et dont la transparence contraste avec la teinte foncée des cellules ; c'est la coupe optique de la couche de sarcode qui règne sur toute la surface des sphérules. Mais en outre nous remarquons dans le plan de contact des cellules voisines une accumulation de liquide, fait déjà constaté par Warneck. Ce liquide va sans doute remplir la cavité de fractionnement, mais une partie est aussi expulsée sous forme de gouttelettes qui sortent généralment au pôle nutritif. J'ai observé une seule goutte chez les Hétéropodes et les Pulmonés aquatiques. . . . La cavité de segmentation, ou blastocèle, reste presque nulle pendant que l'invagination se forme et ne commence à croître qu'après le rétrécissement du blastopore."

The propriety of the use of the term blastocœl or segmentation cavity to designate the lacunar spaces of the mesenchyma of the gastrula, as well as the spaces between the primitive blastomeres, is questionable. To be sure the mesenchymatous lacunæ are derived from the blastocœl rather than from an enterocœl, in Limax at least ; but our choice of terms is not limited to blastocœl and enterocœl, and it seems preferable to apply to those spaces without epithelial lining which lie between the ectoderm and entoderm, and are traversed by loose mesenchymatous cells and prolongations of the ectoderm cells, a term not already set apart for another use. Previous to the formation of these lacunæ, all the cells of the intermediate layer exist as a solid mass obliterating the cleavage cavity. When, however, in Limax the cavity reappears, as in Figure 54, it is as a distinct space bounded by germ layers. It seems better, therefore, to apply to the spaces mentioned in the second quotation from Fol (p. 116) the same term which is used elsewhere for mesenchymatous lacunæ not lined by a distinct epithelial layer, viz. schizocœl.

Rabl ('79, p. 568) notes the presence of a cleavage cavity in the twelve-cell stage of Planorbis, and suggests the possibility of its presence in the eight-cell stage. It attains its maximum size when the embryo consists of twenty-four cells. He mentions the flattening of the blastosphere which follows this maximum condition, but does not speak of an obliteration of the cleavage cavity accompanying it, and considers that the cavity is still present at the time the mesoderm cells sink below the surface. He makes no suggestion of its recurrent nature at any period of its existence.

Brooks ('80, p. 80) mentions in Physa the " presence of a lens-shaped segmentation cavity, which is enclosed peripherally by the union of the two primary segments. This cavity persists from this stage until the completion of segmentation." He does not refer to its recurrent character in the earlier stages of cleavage, nor to the elimination of its contents in whole or in part.

Joyeux-Laffuie ('82), in his work upon Oncidium, a marine form with pulmonate affinities, makes no reference to a cleavage cavity.

From my own observations on Planorbis and Physa, I have no doubt that the recurrent segmentation cavity is found in these forms, as in Limax; but it is not developed in so marked a degree. I wish in this connection to call attention to the fact that the enclosing capsules and albumen of these forms are less dense than those of Limax, and that they are deposited *in the water*. In Planorbis, which has somewhat more yolk than Physa, the cavity does not attain so great a size as in Physa.

I shall not enter into an extended discussion, or a review of the literature of the cleavage cavity in other groups of animals, especially of marine forms. I shall refer mainly to those forms which, by reason of their conditions of development, might be expected to throw light on the significance of the cleavage cavity.

In Spongilla, likewise a fresh water animal, Maas ('90) finds no trace of a cavity in the solid morula stage, though he admits that there is at the four-cell stage the intimation of one, which later entirely disappears.

According to Brauer ('92) a cleavage cavity appears in Hydra at the eight-cell stage, but he makes no reference to a subsequent disappearance of the cavity.

### ROTIFERA.

Zacharias ('85) finds a cleavage cavity in the two-cell stage of Philodina roseola. He does not figure it in the later stages, but speaks of its general appearance in all the eggs whose early stages he had observed.

Zelinka ('91) does not figure any cleavage cavity in the development of Melicerta or Callidina.

### ANNULATA.

I have found no reference to a recurrent cavity in the marine forms of this group. In forms with much yolk, as Nereis, there may be no cavity whatever (Wilson '93); but in forms whose division is nearly equal, as in Eupomatus, a cavity appears at an early stage and persists until gastrulation (Hatschek '86).

Whitman ('78) describes a cavity in Clepsine, which appears very early at the place where the first three planes of division cross one another. Its early and later history is not given. No mention is made of any obliteration or recurrence of the cavity. He suggests that "the blastocœl, whenever it appears, forms as a necessary result of the cleavage process. . . . The explanation of the cleavage cavity depends upon the fact that the cells push each other apart in cleaving."

This explanation was doubtless suggested by the cleavage of Clepsine, where there is considerable difference in size between the micromeres and macromeres, and the less mobile yolk-laden cells adapt themselves less readily to the changes in cleavage than the protoplasmic blastomeres of the egg of Limax. The difficulty of applying this mechanical explanation of the cleavage cavity to the phenomena observed in Limax will be patent to all. The blastomeres, in this form at least, are exceedingly plastic bodies, adapting themselves either to the presence or absence of a cavity, upon which profound changes in their form depend. Furthermore, the "pushing apart" of the cells in cleavage is often the occasion of the obliteration of a cavity rather than its formation; for the cavity, in the early stages at least, is frequently at its maximum just before cleavage, and is obliterated or reduced in size at its close.

Wilson ('89) finds in the four-cell stage of Lumbricus a cavity which he labels "segmentation cavity," and of which he says, it "disappears afterwards and cannot be identified with the true blastocœl," which is described for the thirteen-cell and later stages. The eggs of L. fœtidus, for which this ephemeral cavity is figured, have tough capsules and thick albumen, similar to that of Limax.

Vejdovsky ('88–'92) describes a distinct cavity in the two-cell stage of Rhynchelmis, and refers to the occurrence of a similar cavity in later cleavage stages. It is evident, however, from his figures, that the cavity is not so prevalent as it is in Limax. A similar cavity occurs in the two-cell stage of Allolobophora. A very interesting phenomenon was also observed by him in the six-cell stage of Allurus tetraëder. In the cytoplasm of the micromeres of this stage, a number of large contorted canals appear, which resemble very much the canals found later in the larval excretory cells of the embryo. These canals are filled with a clear fluid and "hängen offenbar zusammen." The accumulation of fluid in the canals results in an increase in the volume of the micromeres, and an *obscuring of* both *cell boundaries* and *nuclei*. Finally, by a powerful contraction the fluid contents are expelled and the micromeres assume their original form and size, the cell boundaries and nuclei again becoming distinct. It is evident that the author regards these canals as intracellular structures. No sections of this stage are figured, and the relation of these canals to cell boundaries is not determined. The fact that the presence of the canals obscures the boundaries between the cells, and that these canals are in continuity, suggests the possibility that they may be *inter*cellular and therefore merely an exaggerated form of the anastomosing intercellular spaces so common in Limax. Vejdovsky does not suggest their relationship to the cleavage cavity, neither indeed does he regard a space found in the two-cell stage as having anything to do with that cavity. His grounds for this view, and his explanation of the phenomenon, are as follows (p. 105): "Die Höhle zwischen beiden Furchungskugeln ist als Ueberrest der Vorgänge zu betrachten, die sich bei der Bildung der Zellmembranen beider Furchungskugeln abgespielt haben. Diese Höhle zwischen den ersten 2 Furchungskugeln ist bereits oft beobachtet und als eine primäre Furchungshöhle (!) gedeutet worden. Es ist überflüssig eine solche Auffassung zurückzuweisen, einmal, dass es unmöglich ist, dass eine Furchungshöhle bereits zwischen zwei ganz gleich gestalteten Furchungskugeln zum Vorschein kommen könnte, ein anderesmal, dass derartige Höhle öfters auch während des späteren Furchungsprocesses zwischen je zwei Kugeln zum Vorschein kommt (vergl. Taf. IX. Fig. 11, 14). Gewiss ist diese Erscheinung von den Verhältnissen der Zell- und Kern-platte abhängig."

In the absence of the evidence upon which these opinions rest, it seems superfluous to discuss them. His suggestion that the formation of the cavity of the two-cell stage is dependent upon the phenomena of the division resulting in that stage is certainly not sustained by the facts. If his opinion were the correct one, we should find a similar cavity in the two-cell stages of all forms, fresh-water and marine alike.

The preceding review of the literature shows that Warneck ('50), Rabl ('79), Fol ('80), and Brooks ('80) have all noted the recurrent character of a cavity in the *early* stages of cleavage in the Pulmonates, but the three later writers have added little to the admirable observations of the first named investigator.

A glance at the summary of the literature on Prosobranch development shows an entire absence of any reference to a recurrent segmentation cavity in the marine forms, unless an exception be made with regard to McMurrich's observations on the cavity in Fulgur. When a cleavage cavity does occur, it appears at a very late stage in the segmentation, is comparatively small, and is never recurrent. The cleavage of the fresh-water Prosobranchs has not been fully studied except in

Neritina, but the cleavage cavity does not seem to be prominent here. It is however well marked in Amnicola.

Among the Lamellibranchs there is the same absence of reference to a cleavage cavity in marine forms, but its recurrent nature is noted in Unio and Anodonta, probably also in Cyclas. A cavity also occurs in Dreissena, but we do not know that it is recurrent. It seems probable that the encapsuled eggs of the non-marine Chaetopods may also present cases of a recurrent cavity.

So far, then, as the literature and my own observations go, it seems that this recurrent cavity is confined to eggs developing in *fresh water or moist situations*, and reaches its maximum manifestation in forms enclosed in thick encapsuled albumen, like Limax. In these outward conditions of environment probably lies the explanation of this phenomenon. It is probably correlated with the nutritive and excretory processes of the egg, especially the excretory, as Warneck long ago suggested, for we have no evidence that the embryo depends in the cleavage stages upon the surrounding albumen for its nutriment. The latter serves mainly as a protective covering during these stages, though later it is certainly used as food by the growing embryo. The metabolic processes taking place in the protoplasm of the blastomeres may be attended by the endosmosis of water from the surrounding albumen and its subsequent exosmosis. That part which passes out from the cell along the facets of contact with the other cells or on its inner surface, when such exists, contributes toward the formation of a cleavage cavity in some of its varying manifestations. When however the egg, or its envelopes, is bathed by a changing medium, as is the case with fresh-water and marine forms, the cavity is reduced or is altogether wanting, it being probable that the changing medium facilitates the solution and removal of the waste products from the surface of the egg. This is especially true of marine forms where the presence of the salt in the bathing medium doubtless facilitates the solution of the albuminous matters, and it is in these forms that the cavity is never recurrent and rarely present during cleavage. The eggs of the land Pulmonates, lacking as they do the salt, or even a changing medium, have the further disadvantage of a coating of dense albumen. This and its thick envelopes must necessarily impede the processes of excretion and respiration, a hindrance which may be in part removed by the increase of the osmotic surface attendant upon the formation of the cleavage cavity, and also by the forcible removal of the products of excretion by the expulsion of the contents of the cavity. That there exists a physiological necessity for some such process is evidenced by the enormous development of larval excretory and respiratory organs in these encapsuled embryos; for it is in these forms that the primitive kidneys reach a maximum development, and the pulsating head vesicle and pedal sinus (podocyst or amnion of Jourdain) are found.

A large amount of yolk in forms subjected to a fresh-water environment, as Neritina, may conduce to the suppression of this ephemeral recurrent cavity. Its action may be purely mechanical, or it may perhaps be physiological, in that the process of cleavage, and therefore that of metabolism, take place less rapidly in such forms than in cases where there is less yolk and approximately equal cleavage prevails.

In conclusion, then, it may be said that the existence of a cleavage cavity is dependent more upon the physiological necessities of the egg than upon the internal processes of cell division, or the mechanical necessities of cleavage, and that its significance is preeminently physiological rather than morphological.

### 3. *Experimental.*

Fortunately the effect of salt in the surrounding medium is a matter that can be tested by actual experiment. As the eggs of Limax must be placed for examination in water, — an unnatural environment, — it has seemed best not to employ these, inasmuch as the water itself introduces a disturbing factor. Water very readily penetrates the membranes of the egg of Limax, and the albumen absorbs it so that the eggs become quite turgid. Accordingly, recourse was had to the eggs of fresh-water forms where it is not necessary to remove the eggs from their natural environment for experimentation. For this purpose the eggs of Amnicola limosa and Physa heterostropha were used. An egg mass of Physa showing the early stages of cleavage was divided into two equal parts, one of which was kept in the normal water of the aquarium while the other was placed in a salt solution made from the same water. The eggs were then kept under continuous observation, the phases of cleavage, and the size of the cleavage cavity in units of the ocular micrometer were recorded for both lots of eggs. There is some variation in individual eggs as to the rate of development, so that the observation of a number of eggs is desirable, in order that the predominant condition may be taken as the typical one.

The eggs of Physa in the four-cell stage with a maximum cavity were placed in 0.75% salt solution. The elimination of the contents of the cavity occurred very soon afterwards, and slightly earlier in the eggs in the salt solution than in those under normal conditions. These later proceeded to cleave normally, forming a new cavity after the cleavage, which followed close on the obliteration of the cavity. The eggs in the salt water did not divide, nor did a central cavity reappear, small lenticular spaces only being formed. All further activity seemed to be suspended during the four hours that the eggs were kept under observation. A portion of this lot was removed to fresh water after an exposure to the salt solution for an hour and forty minutes. In the course of an hour more cleavage took place, the cells passed through the rounded and flattened conditions, but during the two hours in which the eggs were observed *no* cavity appeared. These eggs seemed to be in a normal condition on the following morning. Cleavage had not advanced in the least in the eggs which remained in the 0.75% solution over night.

The result of this experiment seems to show that the sudden transfer of the eggs to the 0.75% salt solution is inimical to their further development, and that it may have some influence in retarding the appearance of the cleavage cavity when they are restored to fresh water.

A trial of 0.38% salt solution gave approximately the same results.

When, however, the eggs of both Physa and Amnicola were placed in a 0.19% or 0.10% solution, cleavage was at first slightly delayed, occurring from five to fifteen minutes later than in the control eggs in the fresh water. After this initial delay, the cleavage seemed to progress in both lots with equal rapidity. With regard to the cleavage cavity, however, the two lots of eggs presented decidedly different results. When the transfer was made to the salt solution a maximum cavity was already present in both lots. Elimination occurred approximately at the same time in both, but the subsequent reappearance of the cavity in the eggs in the salt solution was delayed from fifteen to thirty minutes, and it never reached the size of that in the eggs in the fresh water. For example, the cavity in the control eggs attained a diameter of five to seven units, while that of the eggs in the salt solution was only three to four at the time of elimination. There were, however, a very few cases in which the cavity reached a diameter of five units.

These somewhat limited experiments seem to accord very well with the observations on the cleavage cavity in fresh-water and marine forms, and with the interpretation given to the cleavage cavity in the preceding pages. They are also interesting in the light of Gruber's ('89) experiments upon fresh- and salt-water Protozoa. When a species common to both environments, as Actinophrys sol, is transferred from salt to fresh water, there is a marked increase in the vacuolation of the protoplasm.

This same vacuolation is characteristic of the fresh-water forms, as contrasted with forms having a marine habitat. The reverse experiment has an opposite result, — a reduction of the vacuolation in the individual when gradually transferred to salt water. Strictly marine forms, as Amœba crystalligera, also show a marked development of vacuolation when they are brought into fresh water. These phenomena seem to show an increased activity of the protoplasm in the absorption of water, and a corresponding increase in the excretory function is also indicated by the much greater activity of the contractile vacuole in fresh-water as compared with marine forms. The physiological action of the recurrent cleavage cavity of the Pulmonates is strikingly suggestive of the contractile vacuole of the Protozoa. The morphological distinction, that the one is intracellular while the other is intercellular, militates however against the homology of the cleavage cavity and contractile vacuole.

## VI. BLASTOPORE AND GASTRULATION.

I have already called attention in the preceding pages to the changes in form characteristic of the stages of cleavage there discussed. The same causes produce similar changes in the later stages. We encounter rounded embryos with a central cavity (Plate VII. Fig. 47), and also much flattened individuals (Plate VII. Fig. 50). The latter are more common, and very generally present a more or less quadrangular outline, the sides of which are parallel to the first two planes of cleavage, i. e. to the antero-posterior and transverse axes of the embryo; the two or four mesoderm cells are symmetrically placed adjacent to the posterior side.

In the case of two embryos, not figured, the mesoderm occupies a different position with reference to these four sides. Instead of lying adjacent to one of the sides, it lies in one angle, a position suggestive of the condition found in the forty-four-cell stage of Figures 39 and 40 (Plate VI.), where the primary mesoblast does not seem to have undergone a shifting into the median plane of the egg. In these cases it would seem to be necessary to orient the egg after the manner of Blochmann ('81) and Rabl ('79), with the first two cleavage planes cutting the axis of bilateral symmetry at an angle of 45°.

It is in these flattened quadrangular embryos, containing from one hundred to one hundred and twenty cells, six or eight of which are mesoderm, that the first traces of gastrulation occur. Previous to this epoch the ventral face, i. e. vegetative pole, of the embryo has a much more rounded contour than the animal pole. The blastoporic invagination now appears as a broad shallow depression, involving a large part of the median surface of the vegetative pole. It is deeper at its rounded anterior margin and gradually diminishes in depth posteriorly. Figures 43 and 44 (Plate VII.) give the appearance of the depression as seen from the surface at this stage. Figure 48 (Plate VII.) is a sagittal section through the lateral margin of the depression, and Figure 49 is a median sagittal section, the anterior end being at the left in both figures. Figures 45 and 46 (Plate VII.) represent respectively the posterior and anterior regions of the blastoporic tract in transverse section.

The dorsal surface also frequently shows a slight depression at this period. This may be due to the temporary obliteration or reduction at this time of the cleavage cavity, which is bounded laterally by the two bands of mesoderm (Plate VIII. Figs. 46, 48–50). The posterior end of the embryo is now slightly broader than the anterior, Figure 44 (Plate VIII.). The broad ventral depression continues to deepen at the anterior end, and becomes narrower throughout its whole length. This results in a flattened embryo with an elongated median depression deepest at its anterior end.

Such flattened embryos with an elongated blastopore have been figured by Lereboullet ('62) and Lankester ('74) for Lymnæus, and by Rabl ('79) for Planorbis. Fol ('80), who does not figure this stage of the Pulmonate embryo, states that he has not found embryos so much flattened as those described by Lankester. The earlier writers upon Limax have passed over this stage in silence, though Lankester ('75, Plate IX. Figs. 21, 22) figures two gastrulæ of Limax agrestis, both of which appear to be of a later stage, showing considerable difference in size between the cells of the two outer layers.

The anterior border of this deepening blastoporic trough becomes more abrupt, and the lateral borders more sharply marked out, while the depression of the posterior region is gradually obliterated. The most marked change that accompanies this growth of the invagination is the increase in size of the anterior end of the embryo. Viewed from the ventral (Fig. 44, Plate VII.) or dorsal surface, it has had, up to this time, a rounded quadrilateral outline, usually with the posterior end the larger; but in the stages represented in Figures 51–53 (Plate VIII.), the anterior end shows a marked increase in thickness as well as a lateral expansion. The thickening and lateral expansion of the anterior end are brought about by two influences, — the deepening invagination, and the accumulation of mesoderm in the antero-lateral region of the embryo. The blastoporic trough has now closed gradually from behind forward until there is a laterally compressed, cone-shaped pit directed antero-dorsally, and occupying a region at the vegetative pole directly opposite that where the polar globules are located, i. e. the blastopore at this period occupies a position corresponding to the centre of the vegetative half of the egg.

The "landmarks" which assist in the orientation of this stage are: (1) The two lateral masses of mesoderm, now in continuity at the thickened region anterior to the blastopore, but separated posteriorly in the mid-dorsal region, where the ectoderm and entoderm retain their primitive contact. (2) The posterior region of the mesodermal bands, which marks the level of the posterior margin of the blastopore. These lie at the smaller end of the embryo. (3) The lateral projections, which may well be called "velar" projections, for they occupy a position similar to that of the velum in Planorbis. The cells of this region are also somewhat larger than those of the surrounding ectoderm (Plate VIII. Fig. 57). Owing to their constancy and prominence they are a valuable aid in the orientation of the embryo.

At a stage succeeding this, represented in sagittal and transverse section respectively in Figures 56, 57 (Plate VIII.), a considerable transformation has been effected. The whole embryo has increased somewhat in size, owing to the growing vacuolation of the entoderm. The velar projections still persist and serve to emphasize the difference between the anterior and posterior ends of the embryo, as before; but the remnant of the blastopore no longer occupies a median ventral position; it is found at the posterior end of the embryo, Figure 55 (Plate VIII.). The relation of this to the preceding stage is a matter of considerable importance, owing to its bearing on the question of the fate of the blastopore.

It is with considerable hesitancy that the consideration of this perplexing question — the fate of the blastopore — is undertaken, for I cannot bring forward to support my conclusions the decisive evidence that can be offered in other forms, e. g. Umbrella. There are in Limax no definitely fixed and prominent landmarks, such for example as the anal cells of Umbrella. The germ layers themselves are not sharply differentiated from one another by the size of the cells, and the whole matter is further complicated by the existence of the recurrent cleavage cavity, the beginning of the vacuolation of the entoderm, and the development of the head vesicle, all of which contribute to profound changes in the external form of the embryo.

Such evidence as there is seems to lead to the conclusion, that the orifice at this later stage, though posterior in position, is derived from the mid-ventral opening — the anterior end of the blastopore of an earlier stage — by a backward overgrowth of the anterior and lateral margins of that opening, the posterior lip of the blastopore being regarded as fixed, so that the remnant of the blastopore comes to occupy a position corresponding to the posterior lip of the blastopore of the earlier of these two epochs. If this is the case, we should expect to find intermediate stages showing steps in this overgrowth. The earlier stage, Figure 51 (Plate VIII.), shows some trace of it, for the pit of invagination has an antero-dorsal direction, i. e. in a ventral view the anterior lip of the blastopore somewhat overhangs the deeper portion of the invaginated layer, whereas the posterior margin rises obliquely to the level of the ectoderm. This overgrowth is accompanied by an accumulation of mesoderm in the anterior region. Although I have examined hundreds of embryos of about this stage, many of them killed especially for the determination of this question, very few good illustrations of this overgrowth have been observed. Figure 53 (Plate VIII.) is a postero-ventral view of such a stage, showing the thickened anterior end with its velar projections. Occupying the mid-ventral region is an elevation which overhangs the site of the mid-ventral blastopore, whose posterior region is now marked by a trough-like depression. Figure 54 (Plate VIII.) is a nearly sagittal section, slightly oblique, through another egg of such a stage, showing the overhanging anterior lip and its contained mesoderm cells. Owing to the obliquity of the section the contact of the ectoderm and entoderm in the mid-dorsal region is not shown in this section. That such an overgrowth as I have suggested takes place is also shown by the conditions found in the later stage itself.

Figures 56 and 57 (Plate VIII.) show that the dorsal wall of the archenteron is much more vacuolated than the more recently formed ventral wall. They also show that there has been an accumulation of the mesoderm in this ventral region, and that the cells of the ectoderm are smaller in the ventral than in the dorsal half of the embryo. All of these facts seem to point to a more rapid growth in this mid-ventral part of the embryo.

The conditions in the mid-dorsal region are of considerable interest. Assuming that the surface of contact between ectoderm and entoderm is constant now, as it has been during gastrulation, except when it is interrupted by the ephemeral cleavage cavity, we find that it no longer occupies the mid-dorsal region, but is shifted about 45° toward the anterior end of the embryo. This shifting is similar to that described by Heymons ('93) for the velar field of Umbrella, and is perhaps homologous with the shifting of the troch in the trochophore larva.

A prominent funnel-shaped opening leads into the archenteron; in the latest stages I have examined it still persists. This is the region where the anus is ultimately found, and I am therefore inclined to the view that this remnant of the posterior part of the blastopore becomes the anus of the adult; it certainly lies in the anal region.

The mouth is formed at a later period by an invagination of the ectoderm on the ventral surface of the embryo. Figure 55 (Plate VIII.) shows an embryo of a stage where the posterior opening leads into the archenteron, and the development of the head vesicle has obliterated all traces of the velar prominences. It will be seen that the ventral lip of the opening is prolonged posteriorly. This is the pedal elongation, which later becomes the podocyst. The shell gland arises on the dorsal surface as an invagination, posterior to the level of the velar region. The enlarged cells premonitory of the invagination are seen in Figure 57 (Plate VIII.).

The conclusions to which I have arrived as to the fate of the blastopore in Limax agrestis are directly contradictory to those of Fol upon L. maximus. According to him the blastopore becomes the permanent mouth. He seems, however, to have entirely overlooked the early stages in the history of the blastopore. His Figures 1 and 2 (Plate XVII.–XVIII.) represent stages in which the overgrowth of the blastopore has already taken place. The polar globules in his Figure 1 have also, it seems, been shifted somewhat, for they lie at the anterior end of the embryo. Furthermore, it is impossible to reconcile his Figures 3 and 4 with his later stages, e. g. Figure 7. It seems much more probable that what he calls the mouth in Figures 3 and 4 is the anus, and that his shell gland is in reality the oral invagination.

In concluding that the anus is formed from this persisting posterior part of the blastopore (actually or potentially), my conclusions agree with those of Bütschli ('77), Lankester ('76), and Blochmann ('83) upon Paludina. Although the anus can thus be referred to the posterior region of the blastopore, it is not so certain, owing to the peculiar manner in which the anus is formed, that the mouth corresponds to the anterior part. It seems probable that in this case the mouth must be regarded as an entirely new structure.

Cambridge, Mass., May 1, 1894.

## ADDENDUM.

Since the completion of the preceding pages, Crampton's paper on *Reversal of Cleavage in a Sinistral Gasteropod* (Annals N. Y. Acad. Sci., Vol. VIII. pp. 167–169, Plate V., March, 1895) has been received. Crampton has followed the cleavage of Physa heterostropha through the twenty-four-cell stage, and a reversal of the direction of the spiral is indicated for every cleavage.

Ann Arbor, Mich., June 24, 1895.

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## EXPLANATION OF THE PLATES.

All figures were drawn from the eggs of Agriolimax agrestis, L., and are from preparations unless otherwise stated. A camera lucida was in every case employed.

*A*, *B*, *C*, *D*, denote the first four cleavage spheres, *A* and *B* corresponding to the anterior quadrants, *B* and *C* to the right quadrants of the embryo. For the meaning of *a*, *b*, *c*, *d*, with their exponents, consult the explanation of the system of nomenclature of cells to be found on pages 40–43.

The first, second, and third cleavage furrows are indicated by the Roman numerals I., II., III., respectively.

Arrows are used to show the common origin of the cells thus connected, the head of the arrow occupying the cell nearer the animal pole of the egg.

### ABBREVIATIONS.

| | | | |
|---|---|---|---|
| *arch.* | Archenteron. | *glb. pol.* | Polar globule. |
| *ast'cœl.* | Astrocœl. | *pd.* | Foot. |
| *bl'po.* | Blastopore. | *pr'c. amœ.* | Amœboid process. |
| *bl'po. a.* | Anterior end of blastopore. | *pr'j. vel.* | Velar projections. |
| *bl'po. p.* | Posterior end of blastopore. | *spa. i'cl.* | Intercellular space. |
| *cav. sg.* | Cleavage (or segmentation) cavity. | *spa. lns.* | Lenticular space. |
| | | *vac.* | Vacuole. |
| *cnch.* | Cells destined to form the shell gland. | *vs. ce.* | Head vesicle. |

## PLATE I.

Figures 1 to 7 drawn from the same living egg. × 275.

Fig. 1. Two-cell stage, beginning of flattened condition, 11.52 A. M.
Fig. 2. Same egg at 12.45 P. M. First trace of cleavage cavity.
Fig. 3. Same egg at 12.50 P. M.
Fig. 4. Same egg at 1.01 P. M.
Fig. 5. Same egg at 1.20 P. M. Maximum size of cleavage cavity.
Fig. 6. First (partial) expulsion of contents of cleavage cavity. 1.30 P. M.
Fig. 7. Same egg at 1.55 P. M. Spindles of the third generation present; the asters of the near ends of the spindles in focus.

Figures 8 to 13 drawn from another living egg of the same laying as Figures 1 to 7. × 275.

Fig. 8. At 3.45 P. M. Division into four cells completed. Typical alternate arrangement of the four blastomeres. Viewed in the direction of the *second* plane of cleavage, therefore perpendicular to the direction of Figures 1 to 7.
Fig. 9. Same egg at 3.55 P. M. Formation of a cleavage cavity.
Fig. 10. Same egg at 4.05 P. M.
Fig. 11. Maximum development of the cleavage cavity. 4.35 P. M.
Fig. 12. Same egg after a gradual total expulsion of the contents of the cavity. 4.45 P. M. Spindles of the fourth generation present.
Fig. 13. Formation of the eight cells of the fourth generation. Persistence of the cleavage cavity. 5.45 P. M.
Fig. 14. Lateral view of two-cell stage. First cleavage plane just completed. Astrocœls present. × 490.

Kofoid.-L

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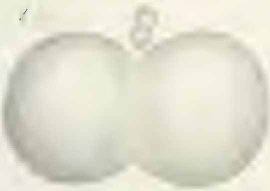

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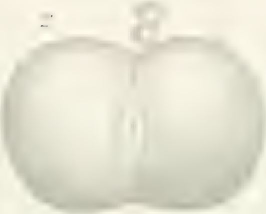

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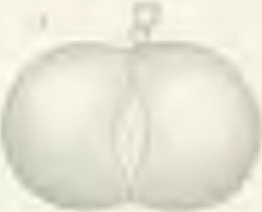

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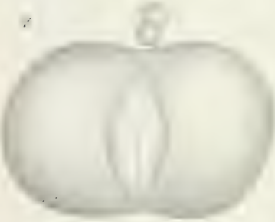

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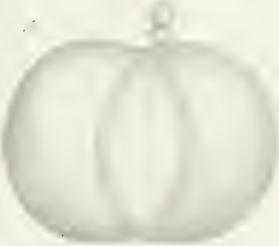

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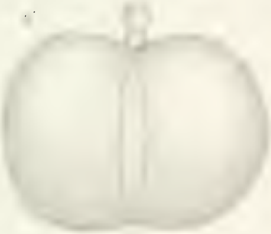

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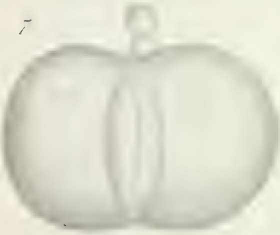

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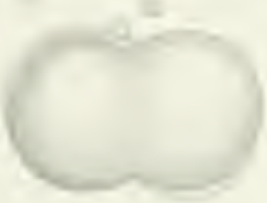

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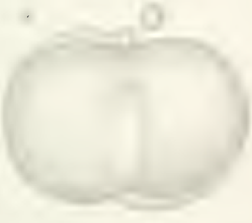

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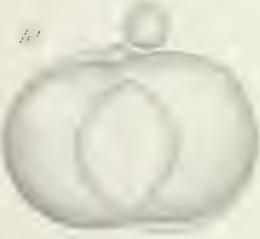

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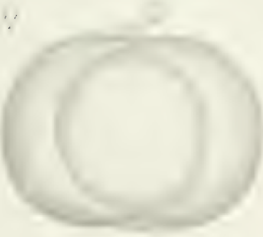

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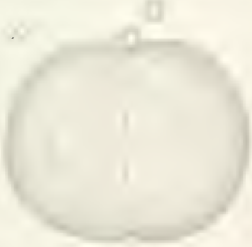

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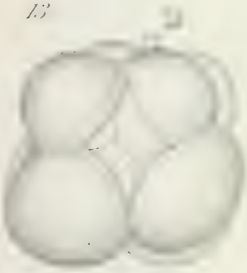

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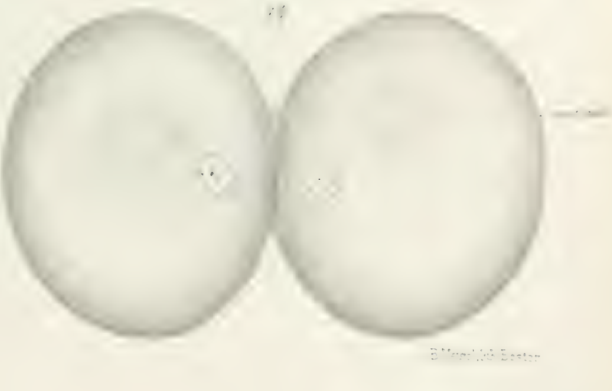


C. A. K. del.

B. Meisel lith. Boston

## PLATE II.

All figures magnified 490 diameters.

Fig. 15. Two-cell stage from animal pole. Spindles of the third generation present. No cleavage cavity. Deeper ends of the spindles (asters of *B* and *D*) shown by lighter lines.

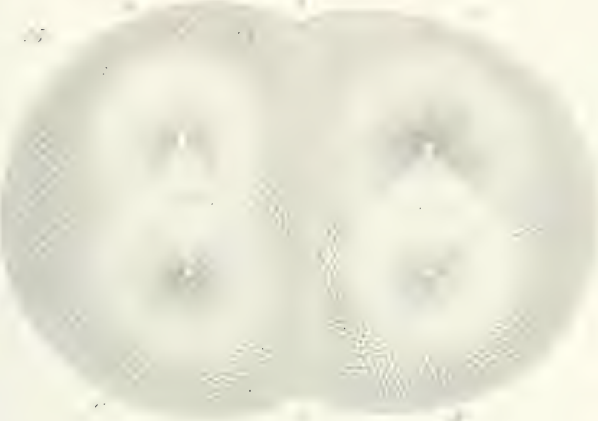
Fig. 16. Four-cell stage from the animal pole. Second cleavage furrow almost completed. Cleavage cavity and lenticular spaces present.

Fig. 17. Four-cell stage from the animal pole. Cleavage cavity present. Spindles of the fourth generation.

Fig. 18. Same egg from the anterior end.

Fig. 19. Eight-cell stage from the animal pole, composed of the two quartets of the fourth generation, $a^{4 \cdot 1} - d^{4 \cdot 1}$ and $a^{4 \cdot 2} - d^{4 \cdot 2}$. Third cleavage plane just completed. Astrocœls present.

15.



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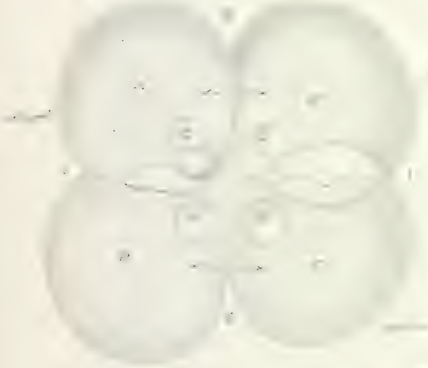

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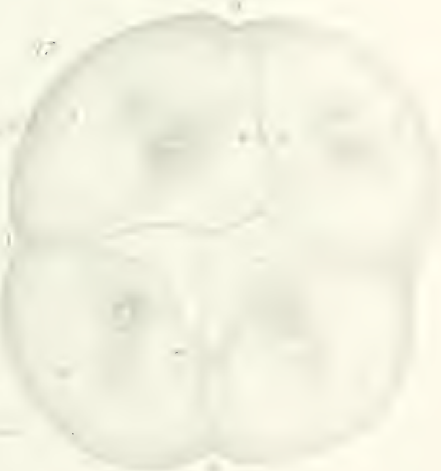

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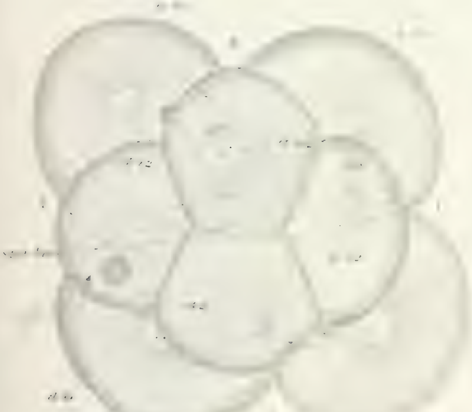

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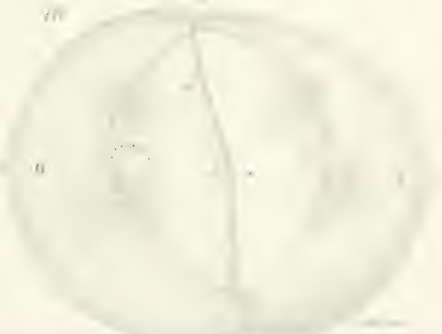


# PLATE III.

All figures magnified 490 diameters.

Fig. 20. Eight-cell stage from the anterior end. Cleavage cavity and lenticular spaces present. Spindles of the fifth generation.

Fig. 21. View of the same egg from the animal pole.

Fig. 22. Sixteen-cell stage viewed somewhat obliquely from the right anterior quadrant, composed of the following cells: $a^{5\cdot1} - d^{5\cdot1}$; $a^{5\cdot2} - d^{5\cdot2}$; $a^{5\cdot3} - d^{5\cdot3}$; and $a^{5\cdot4} - d^{5\cdot4}$. Cleavage cavity present.

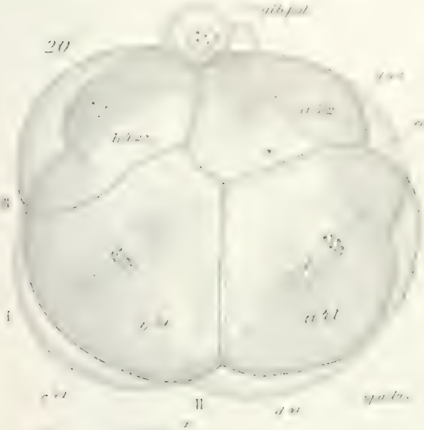
Fig. 23. Lateral view of twenty-four-cell stage. Recent division of quartets resulting in 6.1, 6.2, 6.3, 6.4. Vacuolation at the animal pole.

Fig. 24. Oblique section of same egg. Fifth section in a series of twelve. Intercellular spaces at the animal pole. Cleavage cavity present. $x$, longitudinal section of intercellular space.

Fig. 25. Seventh section in same series.

Fig. 26. Transverse section of an embryo of about one hundred cells, showing vacuolated condition of all three germ layers.

20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a^{4.2}
b^{4.2}
a^{4.2}
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II
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II
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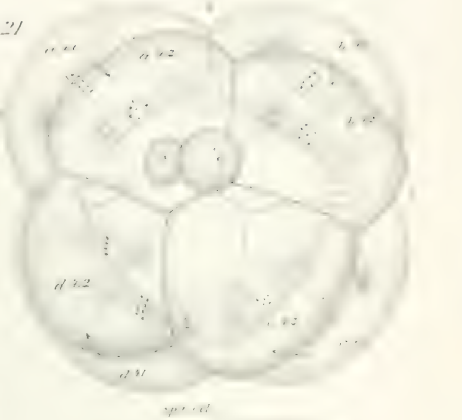
d^{4.1}
sp.a.b.

21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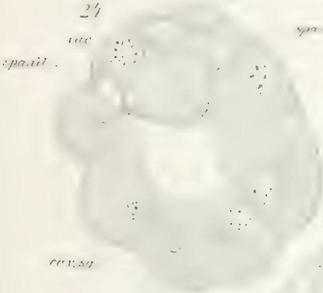
vac
sp.a.d.
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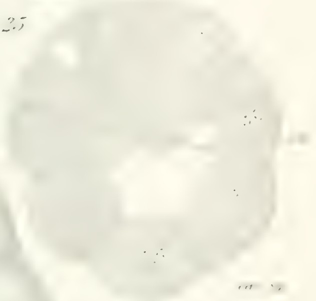
25



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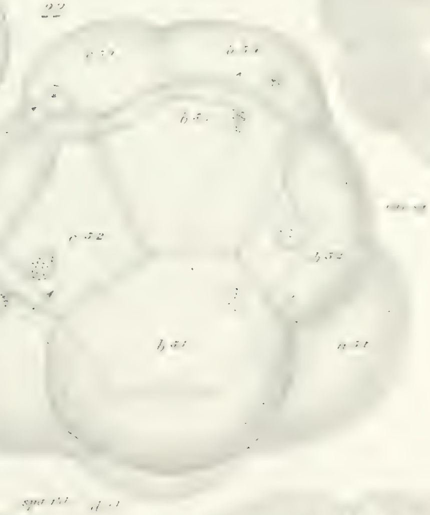
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b^{5.2}
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c^{5.1}
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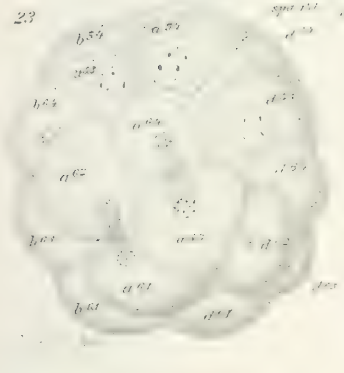
sp.a.d.
d^{5.1}

23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b^{53}
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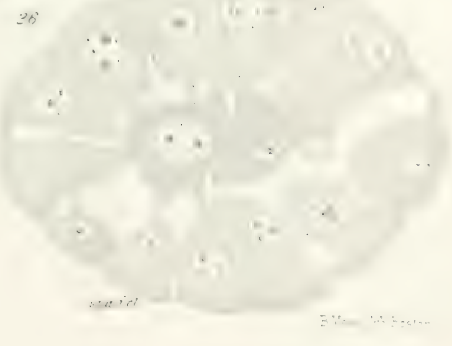
a^{61}
b^{61}
d^{61}

26



B Meisel, lith Boston.

## PLATE IV.

All figures magnified 490 diameters.

Figs. 27-30. Twenty-four-cell stage, composed of the following cells: $a^{5 \cdot 4} - d^{5 \cdot 4}$; $a^{5 \cdot 3} - d^{5 \cdot 3}$; $a^{6 \cdot 4} - d^{6 \cdot 4}$; $a^{6 \cdot 3} - d^{6 \cdot 3}$; $a^{6 \cdot 2} - d^{6 \cdot 2}$; $a^{6 \cdot 1} - d^{6 \cdot 1}$.

Fig. 27. From the vegetative pole.

Fig. 28. From the animal pole, showing vacuolation.

Fig. 29. View of the right posterior quadrant (*c*). Vacuolation of the animal pole.

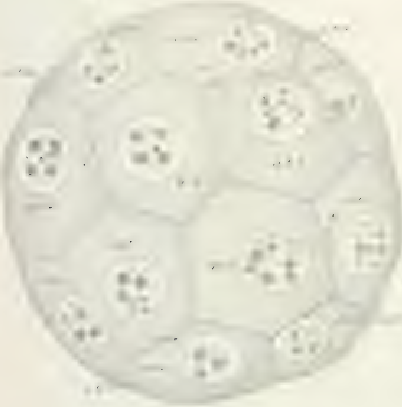
Fig. 30. Optical section along vertical axis cutting the quadrants *b* and *d*.

Figs. 31, 32. Twenty-four-cell stage, similar to the egg shown in Figures 27–30. Division of the quartet 6.2.

Fig. 31. View of the anterior end. Spindle in $b^{6 \cdot 2}$. Polar globule present.

Fig. 32. Same egg from the vegetative pole. Spindles in $b^{6 \cdot 2}$, $c^{6 \cdot 2}$, $d^{6 \cdot 2}$.

27



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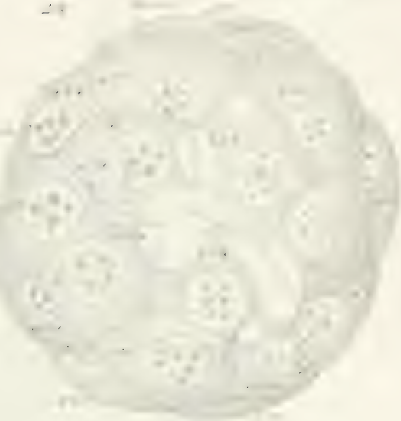

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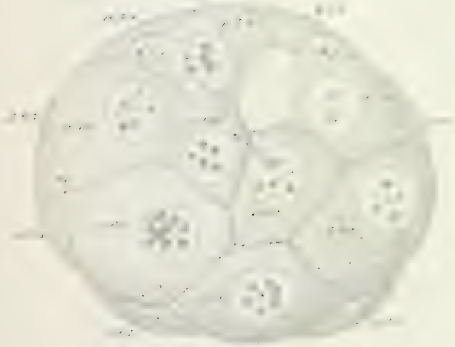

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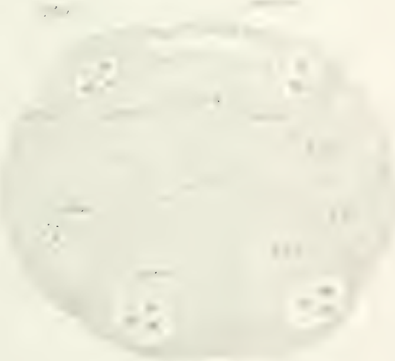

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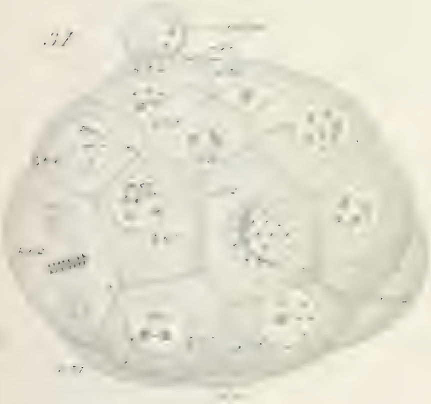

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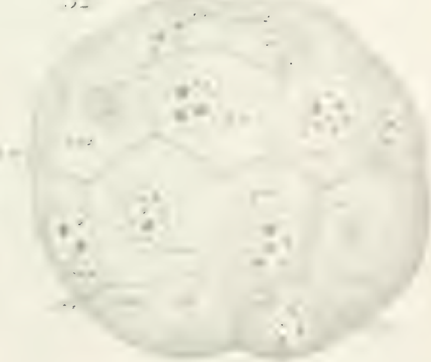


C. A. K. del.

# PLATE V.

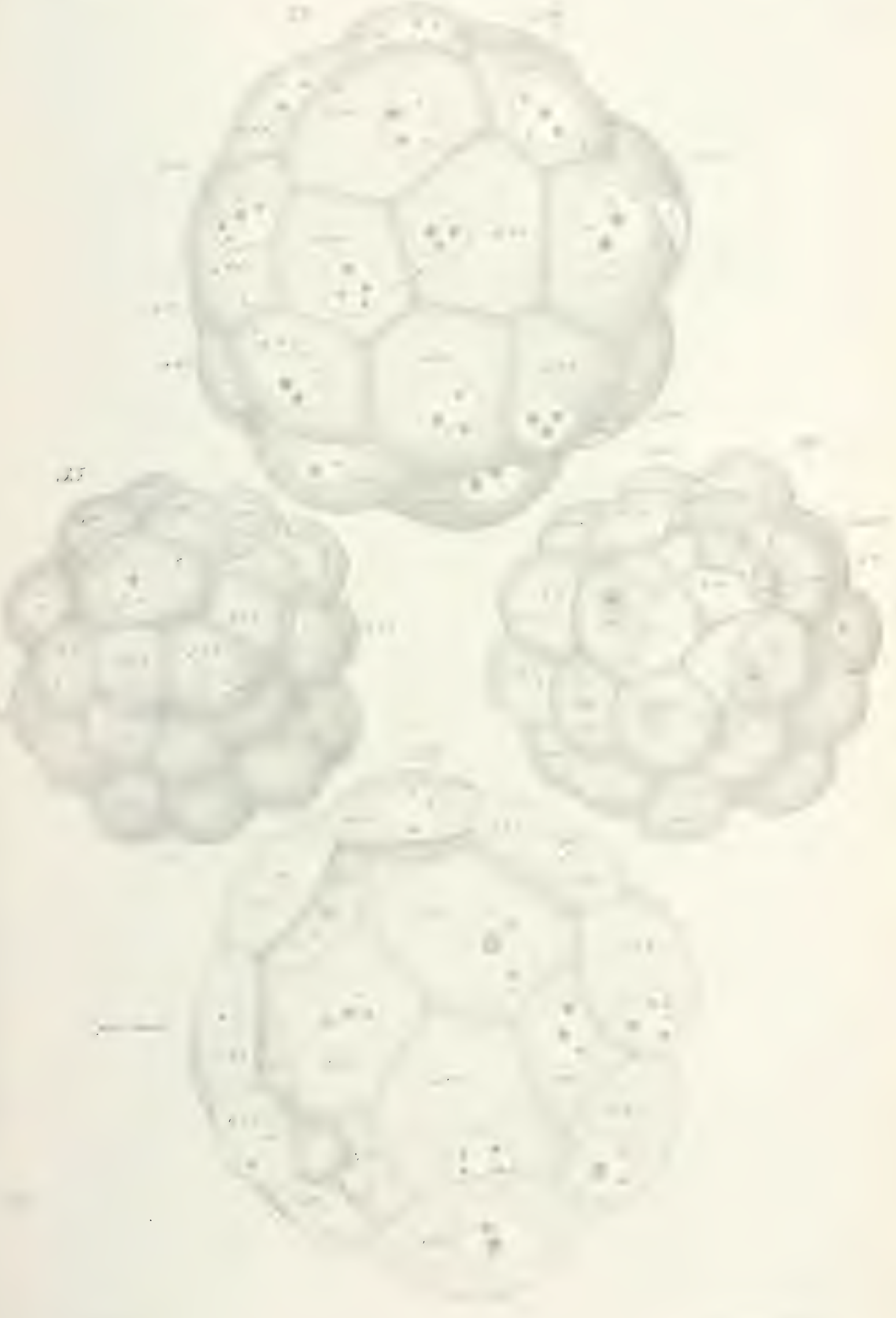
Figs. 33, 34. Twenty-four-cell stage, composed of the following cells: $a^{5.4}-d^{5.4}$; $a^{5.3}-d^{5.3}$; $a^{6.4}-d^{6.4}$; $a^{6.3}-d^{6.3}$; $a^{6.2}-d^{6.2}$; $a^{6.1}-d^{6.1}$.

Fig. 33. View of the left posterior quadrant ($d$) from below. × 490.

Fig. 34. Optical section of egg shown in the preceding figure, and in the plane of the paper, showing the right anterior hemisphere from the inside. Large cleavage cavity present. Amœboid process (*pr'c. amœ.*) on the cell $a^{6.2}$. × 490.

Fig. 35. Twenty-eight-cell, stage composed of the following cells: — $a^{5.4}$ and $\frac{b^{6.8}}{b^{6.7}}$, $\frac{c^{6.8}}{c^{6.7}}$, $\frac{d^{5.8}}{d^{5.7}}$; $a^{5.3}-d^{5.3}$; $a^{6.4}-d^{6.4}$; $a^{6.3}-d^{6.3}$; $a^{6.2}$, $b^{6.2}$, $\frac{c^{7.4}}{c^{7.3}}$, $d^{6.2}$; $a^{6.1}-d^{6.1}$. View from the animal pole. Division of the quartets 5.4 and 6.2. × 510.

Fig. 36. Twenty-five-cell stage, composed of $a^{5.4}$, $\frac{b^{6.8}}{b^{6.7}}$, $c^{5.4}$, $d^{5.4}$; $a^{5.3}-d^{5.3}$; $a^{6.4}-d^{6.4}$; $a^{6.3}-d^{6.3}$; $a^{6.2}-d^{6.2}$; $a^{6.1}-d^{6.1}$. View of the animal pole. Division of $a^{5.4}-d^{5.4}$. Spindles in $c^{5.3}$, $c^{6.4}$. × 510.



# PLATE VI.

Figs. 37, 38. Forty-cell stage, composed of the following cells : —

$a^{6\cdot8}-d^{6\cdot8}$; $a^{6\cdot7}-d^{6\cdot7}$; $a^{6\cdot6}-d^{6\cdot6}$; $a^{6\cdot5}-d^{6\cdot5}$; $a^{6\cdot4}-d^{6\cdot4}$; $a^{6\cdot3}-d^{6\cdot3}$; $a^{7\cdot4}-d^{7\cdot4}$; $a^{7\cdot3}-d^{7\cdot3}$; $a^{7\cdot2}-d^{7\cdot2}$; $a^{7\cdot1}-d^{7\cdot1}$.

Fig. 37. View from the animal pole. × 490.

Fig. 38. View from the vegetative pole. Division of $d^{5\cdot2}$ about to take place. The first mesoderm cell ($d^{7\cdot2}=M$) with a large nucleus lies beneath its sister cell, $d^{7\cdot1}$, only a small portion of it (shaded very dark) coming to the surface. × 490.

Figs. 39, 40. Forty-two-cell stage, composed of the following cells : —

$a^{6\cdot8}-d^{6\cdot8}$; $a^{6\cdot7}-d^{5\cdot7}$; $\frac{a^{6\cdot6}}{a^{6\cdot5}}$, $\frac{b^{6\cdot6}}{b^{6\cdot5}}$, $c^{5\cdot3}$, $\frac{d^{6\cdot6}}{d^{5\cdot5}}$; $a^{7\cdot8}-d^{7\cdot8}$; $a^{7\cdot7}-d^{7\cdot7}$; $a^{6\cdot3}-d^{6\cdot3}$; $a^{7\cdot4}-d^{7\cdot4}$; $a^{7\cdot3}-d^{7\cdot3}$; $a^{7\cdot2}-d^{7\cdot2}$; $a^{7\cdot1}-d^{7\cdot1}$.

Fig. 39. View of the animal pole. Division of $b^{5\cdot3}$ into $b^{6\cdot5}$ and $b^{6\cdot6}$. Vacuolation at animal pole. × 490.

Fig. 40. View of the vegetative pole of the same egg. × 490.

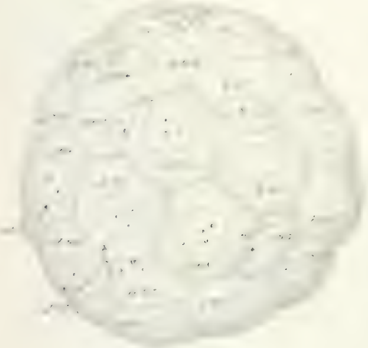
Figs. 41, 42. Forty-five-cell stage, composed of the following cells : —

$a^{6\cdot8}-d^{6\cdot8}$; $a^{6\cdot7}-d^{5\cdot7}$; $a^{6\cdot6}-d^{5\cdot6}$; $a^{6\cdot5}-d^{5\cdot5}$; $a^{7\cdot8}-d^{7\cdot8}$; $a^{7\cdot7}-d^{7\cdot7}$; $a^{6\cdot3}$, $b^{6\cdot3}$, $\frac{c^{7\cdot6}}{c^{7\cdot5}}$, $d^{6\cdot3}$; $a^{7\cdot4}-d^{7\cdot4}$; $a^{7\cdot3}-d^{7\cdot3}$; $a^{7\cdot2}-p^{7\cdot2}$; $a^{7\cdot1}-d^{7\cdot1}$.

Fig 41. View of the animal pole. Recent divisions resulting in $a^{6\cdot5}$, $a^{6\cdot6}$, and $c^{7\cdot5}$, $c^{7\cdot6}$. × 490.

Fig. 42. View of the vegetative pole of the same egg. × 490.

37



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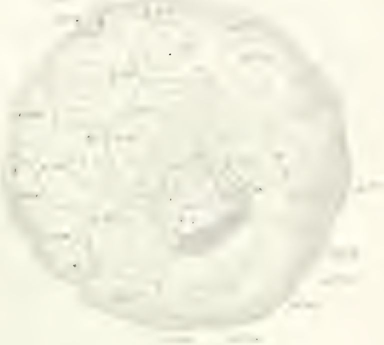

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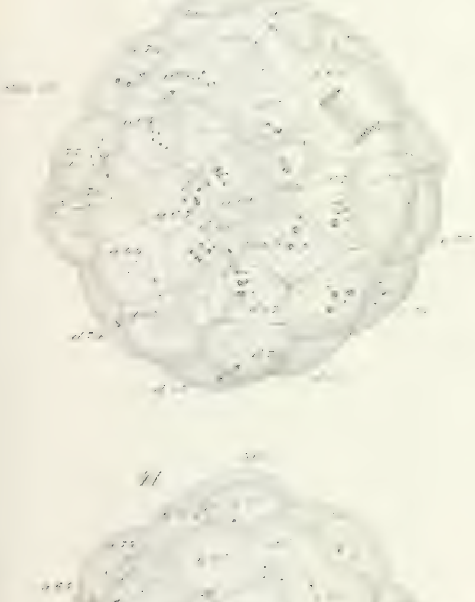

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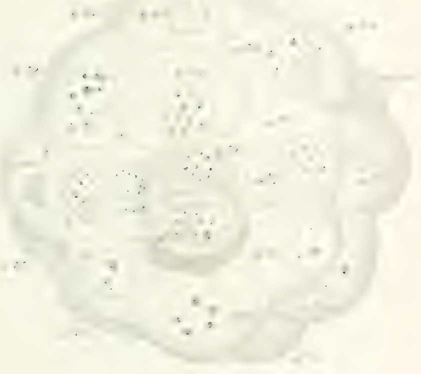

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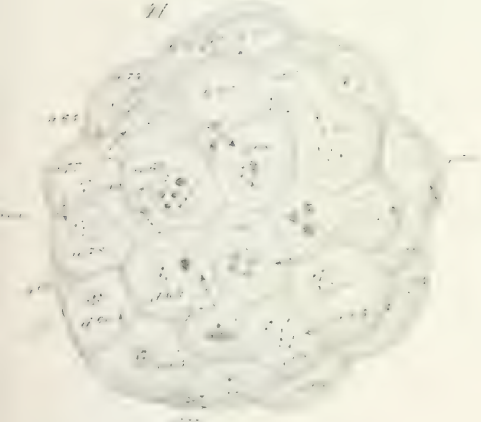

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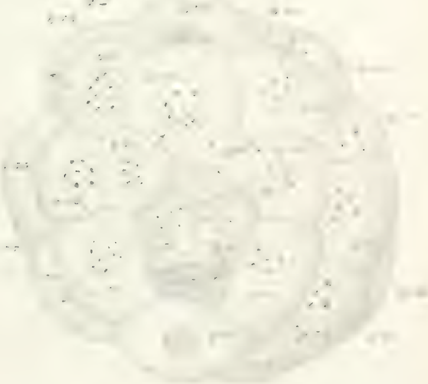


## PLATE VII.

Fig. 43. Young gastrula, seen from the posterior end, showing the broad shallow blastopore. × 300.

Fig. 44. The same, viewed from the ventral surface. × 300.

Figs. 45–50. Sections of gastrula stage. Mesoderm cells shaded dark.

Fig. 45. View of the *posterior* face of the ninth section from the posterior end in a series of nineteen transverse sections, showing broad posterior portion of the blastopore. × 350.

Fig. 46. View of the *posterior* face of the fifteenth section in the same series, showing the deepened anterior end of the invagination. × 350.

Fig. 47. View of the *right* face (animal pole uppermost) of the eighth section in a series of sixteen sagittal sections through a blastula containing eighty cells, showing mesodermal pole cell and cleavage cavity. × 350.

Fig. 48. View of the *left* face (animal pole above) of the eighth section of a series of twenty sagittal sections of an early gastrula, at about the stage of Figure 43, showing cleavage cavity and the mesodermal strand of the left side. × 350.

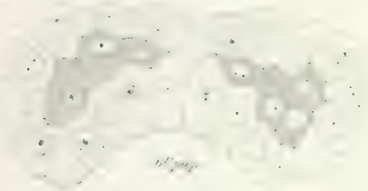
Fig. 49. View of the *left* face of the tenth section of the same series, showing at the right the mesodermal pole cell of the left side. × 350.

Fig. 50. View of the *left* face of the eleventh section of a series of seventeen sagittal sections through an embryo of about the stage of Figure 43, showing the mesodermal strand of the left side. *A*. Anterior; *P*. Posterior. × 350.

43

44

45



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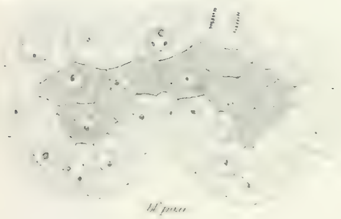

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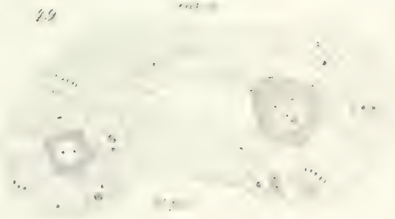

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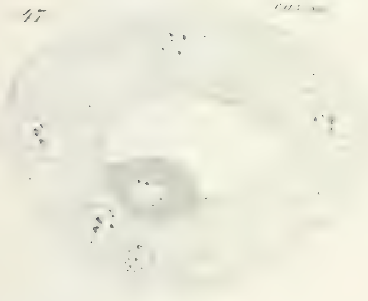

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## PLATE VIII.

Fig. 51. View of the ventral surface of a gastrula, showing blastopore and velar projections. × 350.

Fig. 52. View of the *anterior* face of the eleventh section from the anterior end in a series of nineteen transverse sections of an embryo of the stage of Figure 51, showing blastopore and velar projections. × 350.

Fig. 53. View of the posterior ventral surface of a gastrula somewhat more advanced than that represented in Figure 51. × 300.

Note. — A defect in the shading causes the floor of the median groove (*bl'po.*) to appear elevated into a ridge. There is no such ridge.

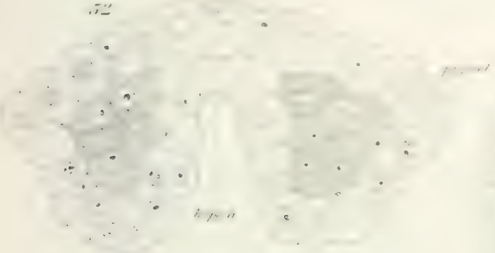
Fig. 54. View of the *left* face of the seventeenth section in a series of obliquely sagittal sections of an embryo of the stage of Figure 53, showing cleavage cavity at the posterior end of embryo. × 350.

Fig. 55. View of the ventral surface of an embryo more advanced than that seen in Figure 53, showing development of the cephalic vesicle and the foot. × 490.

Fig. 56. View of the *right* face of the tenth section of a series of twenty-three obliquely sagittal sections of an embryo with blastopore in the posterior position. × 350.

Fig. 57. View of the *anterior* face of the eighth section, from the anterior end, of a series of sixteen transverse sections, showing archenteron, the velar ridge and enlarged cells (*cnch.*) in the region of the future shell gland. × 300.

52



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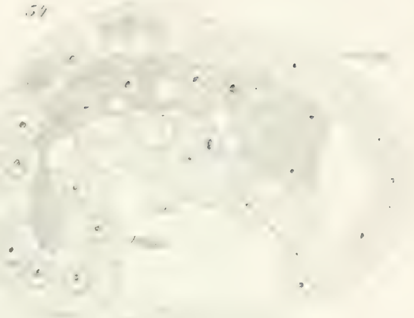

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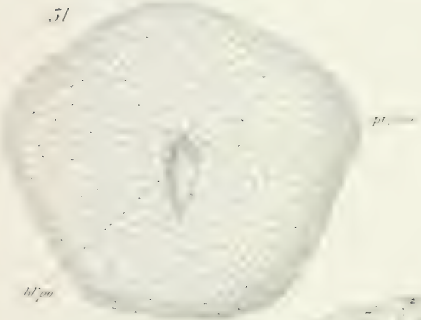

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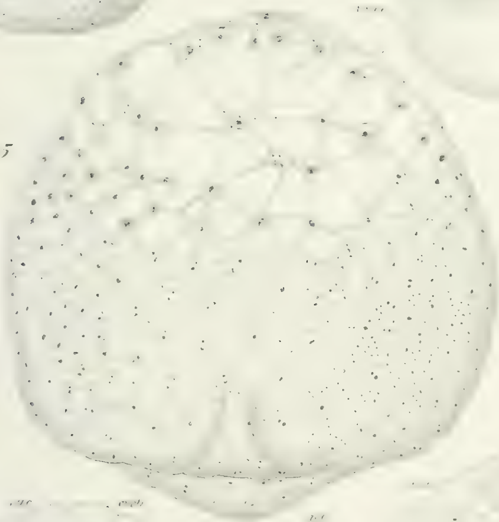

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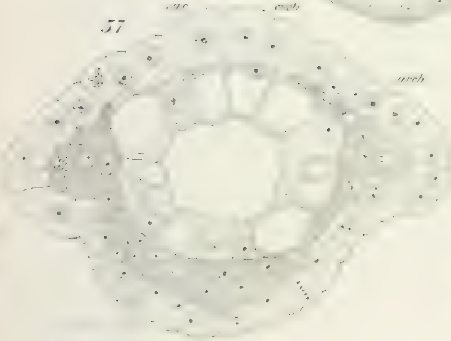

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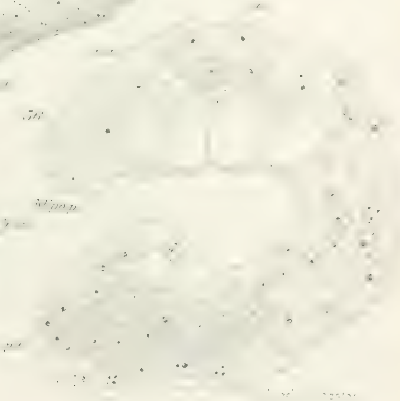

## No. 3. — *Reports on the Dredging Operations off the West Coast of Central America to the Galapagos, to the West Coast of Mexico, and in the Gulf of California, in charge of* ALEXANDER AGASSIZ, *carried on by the U. S. Fish Commission Steamer "Albatross," during* 1891, Lieut. Commander Z. L. TANNER, U. S. N., Commanding.

[Published by permission of MARSHALL McDONALD, U. S. Fish Commissioner.]

## XVII.

## *Birds from Cocos and Malpelo Islands, with Notes on Petrels obtained at Sea.* By C. H. TOWNSEND.

Previous to the time the "Albatross" called at Cocos Island, on February 28, 1891, nothing was known of its birds further than that it was the home of a peculiar cuckoo (*Coccyzus ferrugineus*, Gould), a single specimen of which was obtained during the voyage of H. M. S. "Sulphur," about the year 1840.

Although the collection made by the "Albatross" is a small one, but three additional genera (and species) of land birds having been found, it is interesting as showing ornithological relationship between Cocos Island and the Galapagos Archipelago.

Cocos Island is about 275 miles distant from Costa Rica, in latitude 5° 32′ 57″ N., longitude 87° 2′ 10″ W. It occupies a position nearly midway between the mainland and the islands of the Galapagos group, and with the exception of Malpelo Island, an inaccessible barren rock off the Gulf of Panama, is the only connecting point of land. Like the Galapagos Islands, it is of volcanic origin, and has received its peculiar animal and vegetable forms from the mainland. The American origin of the forms of life upon the Galapagos Islands was demonstrated by Darwin, who made researches there more than half a century ago. It appears from a study of the birds alone, that Cocos Island is similarly a satellite of America, with the added interest of being a stepping-stone to the group of islands beyond it, some of whose ornithological features it bears.

Darwin, the first to study the birds of the Galapagos Islands, described remarkable variations among them, even those inhabiting the same island, that made it difficult to separate them specifically. New forms brought to light by recent explorations, particularly those of the "Albatross," have only served as links to connect the species still more intimately, so that upon the Galapagos Islands there exists the most remarkable grading together of species known to ornithology. This is especially noticeable in the group of finches, in distinguishing which arbitrary measurements are employed, some of the smaller forms closely approaching *Certhidea*, a genus of the *Cærebidæ*. Into the gap between these (*Cactornis* and *Certhidea*) *Cocornis* from Cocos Island seems to fit. The relationship of the Cocos Island flycatcher *Nesotriccus* is equally close to *Eribates* inhabiting the Galapagos. In view of these facts, it is to be regretted that our limited stay at Cocos Island did not permit of a more thorough search for birds, as it is possible that other species exist in the elevated central part of the island which we were unable to reach.

The island is about four miles long by three wide, its central part having an elevation of about 1,700 feet. It is everywhere covered with the densest forest. Cocoanut trees are found upon the higher slopes, and tree ferns abound in the ravines. No tropical forest could be more dense and tangled. The rainfall is doubtless great, as each ravine contains a dashing stream. It is a garden spot in comparison with the arid Galapagos Islands.

I am indebted to the kindness of Mr. Ridgway, Curator of Birds in the National Museum, for much valuable information on the ornithology of the islands of this region.

## COCOS ISLAND.

### Dendroica aureola, Gould.

*Sylvicola aureola*, Gould, Zoöl. Voy. Beagle, Part III. p. 86.
*Dendrœca aureola*, Salv., Trans. Zoöl. Soc. Lond., Vol. IX. Part IX. p. 473.

The two specimens of this warbler secured are not distinguishable from the species (*D. aureola*) inhabiting the Galapagos. Only one other was seen. The species is more closely related to *D. petechia* from Jamaica than the species of the mainland.

## **Cocornis,**[1] gen. nov.

Intermediate between *Cactornis* and *Certhidea* of the Galapagos Islands, but distinguished from both in having a decidedly curved bill. The commissure is without the pronounced angle of the former and the gentle curve of the latter. It is nearest *Cactornis*, which it resembles in feet, coloration, and size, differing in these respects from *Certhidea*, which it resembles more in the slender character of its bill.

### TYPE **Cocornis Agassizi**, sp. nov.

Specific characters similar to *Cactornis scandens*, but with bill more slender and curved, and less rounded, the culmen having more of the character of a ridge.

Hab. Cocos Island.

*Adult male* (Type No. 131680, Cocos Isl., Feb. 28, 1891, C. H. T.). Uniform sooty black, except on under tail coverts, which are tipped with buff. Bill dark brown, lower mandible lighter; legs and feet brownish black. Length (skin), 4.85 inches; wing, 2.60; tail, 1.80; culmen, .56; gonys, .35; bill from rictus, .60; tarsus, .80; middle toe, .50.

*Immature male?* (No. 131682). Sooty black, washed with olive-buff, especially below and on under tail coverts. Length (skin), 4.70; wing, 2.60; tail, 1.75; culmen, .56; gonys, .35; bill from rictus, .60; tarsus, .80; middle toe, .50.

*Adult female?* (No. 131690). Above sooty black, but with the feathers extensively edged and tipped with tawny olive, especially on upper tail coverts, where the black is almost entirely obscured. Edging fainter anteriorly, leaving crown quite dark. Middle and greater wing coverts edged and tipped with russet, tail russet-tipped. Below olive-buff, with the black appearing as a central streak in each feather, except on belly and under tail coverts, which are almost entirely olive-buff. The coloration of the upper parts blends gradually on sides, into that of the lower parts. Quills and tail narrowly edged with russet. Bill pale with dark tip. Legs and feet black. Length (skin), 4.50 in.; wing, 2.50; tail, 1.65; culmen, .50; gonys, .30; bill from rictus, .55; tarsus, .80; middle toe, .50.

In a series of eleven specimens of this bird, six males are sooty black, two of them entirely so (including the type specimen). Two have the bill entirely black. The other dark males have the bill dark brown. Five specimens, two females and three young males, resemble the female described above, and have the bill pale. The young males are somewhat darker than the females, while the full series of males exhibits a regular gradation from the light color of the female to the very dark color of the adult male. This is the only land species that seems to be really common. It is finch-like in its habits, always actively flitting from branch to branch.

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[1] *Cocos* = the cocoa palm from which the island derives its name; *ὄρνις* = bird.

This remarkable species is named for Professor Alexander Agassiz, who was in charge of the work of the "Albatross" at the time Cocos Island was visited.

## Nesotriccus, gen. nov.[1]

Allied to *Eribates* of the Galapagos Islands, but with bill relatively longer and more flattened. Culmen separating the nostrils as a prominent ridge. Gonys less than half the length of lower mandible, terminating in advance of nostrils. Tail relatively shorter.

### TYPE Nesotriccus Ridgwayi, sp. nov.

Specific characters. Distinguished from the allied *Eribates magnirostris* in having no trace of rufous on inner webs of tail feathers, and no ashiness of throat and breast. It is also smaller, with nostrils separated by a sharp ridge.

Hab. Cocos Island.

*Adult male* (Type No. 131691, Cocos Isl., Feb. 28, 1891, C. H. T.). Above olive, brightening to olive-buff on rump; tips of middle and greater wing coverts creamy buff; wings and tail dusky, with narrow olive-buff edgings. Below olive, suffused with yellow, brighter on belly and under wing and tail coverts, darker on breast and sides of head and neck: throat pale buff. Bill dark brown, with posterior half of lower mandible pale yellow. Legs and feet dark brown. Length (skin), 5.25 in.; wing, 2.40; tail, 2.20; culmen, .55; gonys, .35; bill from rictus, .80; depth at base, .18; tarsus, .80; middle toe, .45.

Only one specimen of this bird was obtained, and to the best of my recollection only two or three others seen. They were observed among the tree-ferns in a deep ravine at Chatham Bay. The species is named for Mr. Robert Ridgway, Curator of Birds in the U. S. National Museum.

## Coccyzus ferrugineus, GOULD. (*Nesococcyx*, Cab.)

*Coccyzus ferrugineus*, Gould, Proc. Zoöl. Soc., 1843, p. 104. Zoöl. Voy. Sulph., Birds, I. p. 46.

Only two specimens of this bird were obtained, and not more than three or four others seen. As in the case of the warbler (*Dendroica*) its relationships are with species inhabiting the West Indies, rather than with the forms of the mainland. The genus was not known to the Galapagos Islands until the voyage of the "Albatross," in 1888, when two specimens of *Coccyzus melanocoryphus* Vieill., a mainland form, were secured on Chatham and Charles Islands.

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[1] νήσος = island; *Triccus* = a genus of tyrant flycatchers.

### Anous stolidus, Linn.

*Sterna stolida,* Linn., Syst. Nat., Vol. I. p. 227.
*Anous stolidus,* Ridgw., Proc. U. S. N. M., Vol. XII. p. 116.

Abundant; four specimens collected. This species was noticed as most numerous, flying among the branches of the trees in the forest. The specimens, although resembling *A. galapagensis*, Sharpe, are apparently referable to *A. stolidus.*

### Sula, sp.

Abundant, not collected.

## MALPELO ISLAND.[1]

### Creagrus furcatus (Néboux).

*Larus furcatus* (Néboux), Prev. et des Murs, Voy. Venus, V. Ois., p. 277.
*Creagrus furcatus,* Salv., Trans. Zoöl. Soc. Lond., Vol. IX. Part IX. p. 506.
*Creagrus furcatus,* Ridgw., Proc. U. S. N. M., Vol. XII. p. 117.

I shot four specimens of this rare gull during our short stop at Malpelo Island on March 5th, and saw several others upon the cliffs. The species is doubtless abundant there, as sea birds of several species swarm about the inaccessible summit of the island.

But three specimens of this bird were known prior to the voyage of the "Albatross" to the Galapagos Islands in 1888, when I procured two specimens at Dalrymple Rock, Chatham Island. Malpelo Island is a new locality for *Creagrus furcatus,* the other examples known having all come from the Galapagos, with the exception of one from Peru, and the original specimen procured during the voyage of the "Venus," 1836–39, attributed, doubtless erroneously, to Monterey, California. Unless contained in the Baur and Adams collection, only nine specimens are known at the present time, although the bird was discovered more than fifty years ago.

## PETRELS OBTAINED AT SEA.

### Oceanodroma cryptoleucuera, Ridgw.

Three specimens obtained off Wenman Island, Galapagos, April 4. They were attracted on board by the electric lights used on deck while dredging at night.

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[1] Malpelo Island is a volcanic rock in Lat. 3° 59′ 7″ N.; Lon. 81° 34′ 27″ W. It is less than a mile in greatest length, with a height of over 800 feet. It is inaccessible and without vegetation other than a small patch of bushes.

### **Oceanodroma melania**, Bonap.

This species from the west coast of Mexico has been described by Ridgway as *O. Townsendi* in the Proceedings of the National Museum, Vol. XVI. p. 687, but is probably referable to *O. melania*.

Nine specimens. I obtained the first on March 28, 1889, off Guaymas, the others in 1891; one off Acapulco, April 12th, and the others off Guaymas, April 21st.

### **Halocyptena microsoma**, Coues.

*Halocyptena microsoma*, Coues, Proc. Phila. Acad., 1864, p. 78.

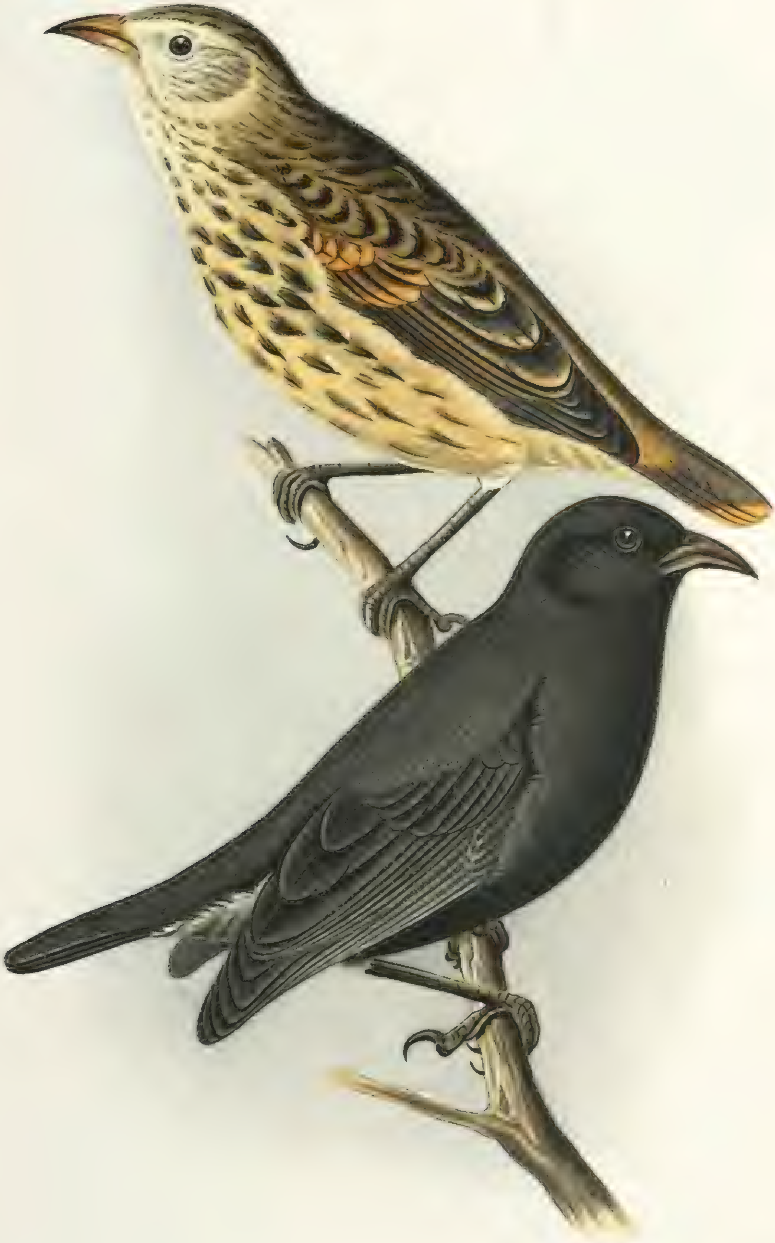
A single individual obtained while the "Albatross" was dredging off Acapulco, April 12th. This is the third specimen known. I procured the second in 1888, off Panama. The original was taken in 1861, off Cape St. Lucas.

### **Procellaria tethys**, Bonap.

Four specimens: two off Chatham Island, Galapagos, March 28th, and two on March 24th, 400 miles east of the Galapagos.

### **Puffinus tenebrosus**, Pelz.

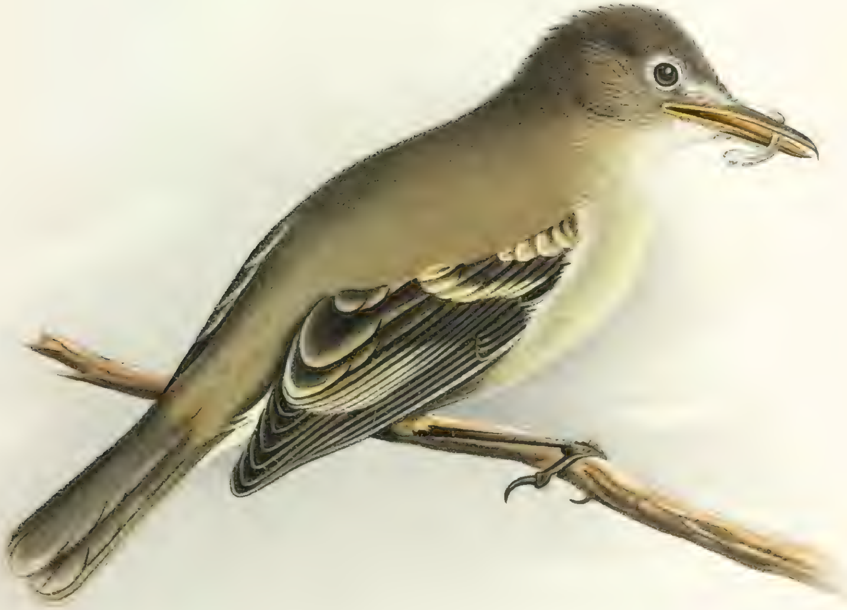
Three specimens: one off Chatham Island, March 28th, the others off Wenman Island, April 4th.



COCORNIS AGASSIZI, Townsend

Adult Male and Female

$\frac{1}{1}$



NESOTRICCUS RIDGWAYI, Townsend

Adult Male

$\frac{1}{1}$

## No. 4. — *Reports on the Dredging Operations off the West Coast of Central America to the Galapagos, to the West Coast of Mexico, and in the Gulf of California, in charge of* ALEXANDER AGASSIZ, *carried on by the U. S. Fish Commission Steamer "Albatross," during* 1891, Lieut.-Commander Z. L. TANNER, U. S. N., Commanding.

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### XVIII.

### *Die Comatuliden.* Von C. HARTLAUB.

Die Ergebnisse der Albatross Expedition sind, wie bereits von *Agassiz*[1] mitgetheilt wurde, auf dem Gebiete der Crinoiden auffallend spärlicher Natur gewesen. Während der Dampfer von andern Echinodermen, wie vor Allem Echiniden, Asteriden und Holothurien reiches Material erbeutete, besteht der ganze Fang an Crinoiden aus nur 7 *Antedon*-Arten und dem interessanten *Calamocrinus Diomedæ,* welchen *Agassiz* schon beschrieben hat.[2] Unter den 84 Dredge-Stationen der Reise sind nur 10 zu nennen, die überhaupt Crinoiden lieferten. Von diesen fallen 6 auf die erste Fahrt, von Panama nach Cocos Island, 3 auf die zweite (3 Stationen bei den Galapagos) und eine auf die dritte Fahrt (Sta. 3424 Las Tres Marias). Ansehnliche Mengen von Exemplaren ergaben nur Sta. 3385, Golf von Panama (*Antedon tanneri* n. sp.), Sta. 3424, Las Tres Marias, und Sta. 3357, nicht weit von Cap Mariato Point, wo u. a. eine Anzahl Antedons aus der *Basicurva*-Gruppe (*Antedon agassizii* n. sp.) und der erwähnte *Calamocrinus* erlangt wurden.

Verglichen mit den Crinoiden Schätzen der *Blake*-Expedition auf der atlantischen Seite Central-Americas war dies negative Resultat auf der pacifischen gewiss sehr überraschend; allein so klein die Zahl der mitgebrachten Arten auch ist, die Albatross-Expedition hat doch unsre Kenntniss von der geographischen Verbreitung des Genus Antedon sehr bemerkenswerth bereichert. Es hat sich nämlich herausgestellt, dass eine Artengruppe dieser Gattung, die man nach den bisher bekannten Vertretern als vorwiegend arctisch und nahezu antarctisch ansah, dies keineswegs ist. Die Eschrichti Gruppe, als deren südlichster Verbreitungspunct auf der nördl. Halbkugel der 43. Grad nördl. Br. angesehen wurde (*Antedon eschrichti bei Halifax*) und welche auf der südlichen Hemisphære die Magelhan Strasse und die Heard Islands als Fundorte hat, ist nicht minder in den Tropen zu Hause. An Individuenzahl nimmt sie in der Albatross-Sammlung sogar bei Weitem die erste Stelle ein, leider auch bezüglich der Schwierigkeit, welche mir die systematische Beurtheilung der beiden Formen gemacht hat, von denen ich nachstehend mit allem bei Crinoidenarten nöthigen Vorbehalte eine als neu beschrieben werde. Der Systematiker für Comatuliden ist ja insofern schlimm daran, als er für die mühsame Begründung neuer Arten selten durch das glückliche Gefühl voller Sicherheit belohnt wird.

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[1] *Agassiz Al.,* General Sketch of the Expedition of the "Albatross" from February to May, 1891, in: Bull. Mus. Comp. Zoöl. Harvard College. Vol. XXIII. No. 1.

[2] *Agassiz Al., Calamocrinus diomedæ* in: Mem. Mus. Comp. Zoöl. Harv. Coll. Vol. XVII. No. 2.

## I. ARTEN MIT AMBULACRALER TÄFELUNG.

### **BASICURVA GRUPPE** Carp. Chall. Rep. XXVI. p. 99.

*10-armige Antedon Arten, deren Radialia und untere Armglieder abgeplattete Seiten haben, und deren Pinnula-Ambulacra meistens getäfelt sind; die zwei äusseren Radialia sind gelenkig verbunden.*

*Uebersicht und Verbreitung ihrer Arten:* —

Gesammtzahl der Arten, 21.

Geringste Tiefe: 49 Faden, Arapura See. — (*Antedon denticulata* Carp.)

Grösste Tiefe: — 1600 Faden, Südsee. — (*Antedon bispinosa* Carp.)

*In Tiefen unter und bis zu 500 Faden,* 13 Arten.

| | | |
|---|---|---|
| 49 Faden, | Arapura See. | *Antedon denticulata* Carp. |
| 88–262 " | Carribean Sea.<br>Str. of Florida. | " *duplex* Carp. M. S. |
| 140 " | Ki Islands. | " *flexilis* Carp.<br>" *longicirra* Carp.<br>" *parvipinna* Carp.<br>" *pusilla* Carp. |

| | | | | |
|---|---|---|---|---|
| 270 | Faden, | Str. of Florida. | *Antedon* | *brevipinna* Pourt. |
| 345 | " | off Japan. | " | *latipinna* Carp. |
| 375 | " | Pacific, off Pangloa Isl. | " | *tuberosa* Carp. |
| 420–550 | " | S. Atl. off Tristan da Cunha, Ascension. | " | *multispina* Carp. |
| 500 | " | Meangis Isl. | " | *aculeata* Carp. |
| | | | " | *gracilis* Carp. |
| | | | " | *valida* Carp. |

*In Tiefen von über* 500–1000 *Faden*, 9 Arten.

| | | | | |
|---|---|---|---|---|
| 420–550 | Faden, | S. Atl. Tristan da Cunha, Ascension | *Antedon* | *multispina* Carp. |
| 630 | " | Kermadecs. | " | *incerta* Carp. |
| | | | " | *echinata* Carp. |
| | | | " | *basicurva* Carp. |
| 630–1350 | " | " und Fiji. | " | *breviradia* Carp. |
| 610–630 | " | " | " | *incisa* Carp. |
| 740 | " | off Portugal. | " | *lusitanica* Carp. |
| 782 | " | off Mariato Point. | " | **agassizii**, Hartl. |
| 950 | " | Port Jackson. | " | *spinicirra* Carp. |

*In Tiefen von über* 1000 *Faden*, 3 Arten.

| | | | | |
|---|---|---|---|---|
| 1350 | Faden, | Fiji. | *Antedon* | *acutiradia* Carp. |
| –1350 | " | " | " | *breviradia* Carp. |
| 1600 | " | Südsee. | " | *bispinosa* Carp. |

## **Antedon agassizii** n. sp.

**Taf. I. Fig. 4, 7, 8; Taf. II. Fig. 16, 18, 19; Taf. III. Fig. 23; Taf. IV. Fig. 26.**

Centrodorsale von mässiger Grösse, kuppelförmig, am dorsalen Ende cirrusfrei und mit kleinen Dornen bedeckt; 15–22 dünne, namentlich in der äusseren Hälfte stark comprimirte Cirren von etwa 40 mm. Länge; dieselben stehen in 2 und stellenweise 3 Horizontalreihen und bilden bisweilen auch Verticalreihen. Grösste Anzahl der Cirrusglieder etwas über 60; davon die beiden ersten kurz, das dritte länger, das 4. mal solang als das dritte, das 6. am längsten und an langen Cirren 2½ mm. messend; von ihm ab nimmt die Länge der Cirrusglieder rasch ab bis circa zum 20. Gliede, auf welches eine Reihe kurzer, allmälig kleinerwerdenden Glieder folgen; im Verlaufe dieser letzteren ist die dorsale Kante des Cirrus deutlich gezackt. Manche Cirren haben an den letzten 30 Gliedern einen ausgesprochenen Dorn. Dorn des vorletzten Gliedes mitunter schwach.

*Erste Radialia* eben sichtbar; die zweiten kurz, seitlich vollkommen frei, und für das rhombische Axillare, mit welchem sie einen schwachen Buckel bilden, nicht eingeschnitten. *Axillare* rhombisch, distalwärts stark verbreitert und hier zuweilen mit vertikal abgeplatteter Seite den Nachbaraxillarien angelagert. Zweites Radiale und Axillare sind mit kurzen stumpfen Dornen besetzt. Manchmal sind einzelne 2-gliedrige Distichalserien vorhanden.

10–12 *rundliche schlanke Arme* von beträchtlicher Länge und ganz rauher Oberfläche. Die Armglieder bis zur zweiten Syzygie tragen auf ihrem proximalen und distalen Rande kleine aufrechtstehende stumpfe Dornen nach Art derer auf den Radialien.

*Erste Brachialia* ziemlich kurz, in der hinteren Hälfte ambulacralwärts verbreitert und hier mit vertical abgeplatteter Seitenfläche dem ersten Brachiale des Nachbarradius angelagert. Diese Seitenfläche bildet die Fortsetzung der des Axillare und somit eine Gesammtfläche mit dieser. — Auf der Innenseite berühren sich die ersten Brachialia in ihrer proximalen Hälfte.

*Zweite Brachialia* etwas länger als die ersten und distalwärts verbreitert. Sie sowohl als die 3. Brachialia stehen in enger Berührung mit dem 2. und 3. Brachiale des Nachbararms; diese Berührungsstelle ist, da sie ganz ambulacralwärts liegt, schwer zu bemerken. Sie ist von der gleichen Contactfläche des ersten Brachiale durch eine Lücke getrennt. — Die auf das 3. folgenden 7 Glieder sind etwas breiter als lang und in der Mitte eingeschnürt. Vom etwa 9. an nimmt die Länge der Armglieder zu, und ihre Form beginnt mehr dreieckig zu werden, und so bleibt sie ungefähr vom 20. bis zum 30. Gliede. Vom etwa 23. Gliede an ($2\frac{1}{2}$ mm.) nimmt die Länge wieder allmälig ab. Auf die dreieckige Gliedform folgt eine mehr trapezoide, und in der zweiten Armhälfte erschienen die Glieder dütenartig in einander gesteckt (Taf. II. Fig. 16). Die distalen Ränder sämmtlicher Armglieder sind stark aufgeworfen und in der zweiten Armhälfte fein dornig. Hier gehen von ihnen Längsriefen aus, welche über die distale Gliedhälfte hinziehen.

Die Dicke der Arme nimmt ganz allmälig ab; die Armlänge beträgt bis 170 mm.; die Zahl der Armglieder bis zu 130.

Erste Syzygie im 3. Brachiale; zweite vom 13.–15., dann in Abständen von 2–3 Gliedern.

Die *Pinnula des zweiten Brachiale* (Taf. II. Fig. 18) ist ziemlich steif, 9–11 mm. lang und zählt 16–18 kurze, glatte Glieder, von denen die ersten 4 — vor Allem aber die 2 ersten — breiter als lang sind. Es ist diese Pinnula an ihrer Basis seitlich abgeflacht und breit und nach etwa dem 6. Gliede spitzt sie sich schnell und fein zu. Ihre äusseren Glieder haben feine, bedornte Distalränder; die Glieder der proximalen Hälfte aber glatte; jedoch sind bei ihnen die ambulacralen Kanten gezackt. Das 2.–5. Glied hat eine Art Kiel; die Verbindung der mehr basalen Glieder unter sich ist eine lockere und dies in erhöhtem Grade an der folgenden Pinnula, deren Basalglieder dementsprechend eine etwas andre Form haben; doch sind auch diese etwas abgeflacht. Es hat das aber schon bei den unteren Gliedern der 3. Pinnula, die rundlicher ist, ein Ende.

Die *Pinnula des* 4. *Brachiale* ist kürzer und hat etwas weniger Glieder, auch ist sie weniger steif und bedeutend feiner gebaut; sie hat wie die folgenden Pinnulæ vorspringende, feine bedornte distale Ränder.

Die dann kommenden Pinnulæ werden bei etwas abnehmender Länge (geringstes Maass 6 mm.) noch zierlicher und ihre Glieder werden länglicher. Vom 14. Brachiale nimmt die Länge der Pinnulæ wieder zu bis zu einem Maximum von 23 mm., und 22–23 Gliedern. Diese letzteren werden bedeutend länger als breit mit Ausnahme der 2 ersten und besonders des Basalgliedes, welches kurz und breit bleibt und eine trapezoide Form hat.

Die *Pinnula des* 3. *Brachiale* ist etwa 2 mm. kürzer als die des zweiten und entschieden schwächer.

Ambulacralfläche der Arme und Genitalpinnulæ deutlich getäfelt. Die Pinnulæ haben Seitenplatten (Taf. 2, Fig. 19).

*Sacculi* klein und wenig auffallend; mit den Seitenplatten alternirend.

*Scheibe* stark eingeschnitten; vollständig getäfelt. 9 mm. Dm.

*Färbung* in Spiritus gleichmässig grünlich gelb, zum grössten Theil durch den stark ebenso gefärbten Alcohol ausgezogen.

*Klafterung* bis 35 cm.

*Fundorte* Station No. 3357, nicht weit von Cap Mariato Point (Bucht von Panama), in 782 Faden, "Modern Greensand"; Bodentemperatur 38,5 F. — Station No. 3408, Galapagos, 684 Faden, Globigerinen Schlamm; Bodentemperatur 39,5 F. — Station No. 3409, Galapagos, 327 Faden, Schwarzer Sand; Bodentemperatur 42.3 F.

Bemerkungen: —

Station No. 3408 lieferte ein kleines 11-armiges Exemplar. Es ist dadurch ausgezeichnet, dass seine erste Pinnula weniger glatte Gliedränder hat, als es die Regel ist. Sie sind fein bedornt, was bei den übrigen Exemplaren nur an den äussersten Gliedern der betr. Pinnula der Fall ist.

Station 3408 ergab zwei noch kleinere Exemplare (Armlänge 4½ cm.) und 2 ganz winzige, bei denen das erste Radiale vollkommen sichtbar ist und stumpfe, kurze, aufrechtstehende Dornen besitzt.

Bemerkenswerth für die neue Species ist neben dem Dimorphismus in der Anzahl der Arme, *die Beschrenkung der wandartigen interradialen Contactflächen auf das Axillare und erste Brachiale,* und der Umstand, dass dieselben sogar vollkommen fehlen können. Die 2. Radialia sind seitlich ganz frei; sie berühren sich nur an den Aussenkanten ihres verbreiterten proximalen Endes. Zwischen dieser Berührungsstelle und dem Contact der Axillaria befindet sich ein offner Zwischenraum, ein Loch. Aehnlich scheint sich *Antedon multispina* Carp. zu verhalten, doch ist der Autor geneigt bei ihr dies Vorkommen als Jugendcharakter zu deuten. ["The 2 outer radials, especially the second, which are very short can hardly be described as wall-sided," Chall. Rep. XXVI. p. 117.]

Zu beachten ist sodann die Klafterung von *Antedon agassizii,* welche mit 35 cm. die fast aller andern Arten der Gruppe weit übertrifft. Am nächsten kommt ihr *Antedon valida* Carp. mit "25 cm. spread." Uebertroffen wird ihre Grösse durch *Antedon flexilis* (Basicurva und Spinifera Gr.) mit "55 cm. spread" und *Antedon robusta* (Spinifera Gr.) "spread nearly 50 cm."

Entschiedene Aehnlichkeit verbindet die Art durch die Bedornung ihrer Radialia and unteren Brachialia mit *Antedon bispinosa,* bei welcher die Kelchglieder und die untersten Brachialia der Abbildung nach zu urtheilen (Chall. Rep. XXVI. Pl. 20) nicht nur an den Rändern sondern auf ihrer ganzen Oberfläche mit kleinen stumpfen Dornen besetzt sind. Bei *Antedon agasiizii* geht indessen dieser Schmuck weiter den Arm hinauf als bei jener Art und die kleinen ganz aufrechtstehenden Dornen sind auf den proximalen und distalen Rand eines jeden Gliedes beschränkt, in der Weise, dass jede Gliedverbindung durch 2 Querreihen von Dornen gekennzeichnet ist.

Bezüglich das Calyx verweise ich auf Tafel 1, Fig. 4, 7, 8. — Die Cirrusgruben sind ziemlich gross und besitzen einen ansehnlichen Gelenkkopf. Die ventrale Fläche des Centrodorsale ist annähernd pentagonal und die 5 Ecken ragen etwas vor. Die dorsale Fläche des radialen Pentagons zeigt Spuren eines Basalsterns. Im Trichter erkennt man, etwas tiefer als der dorsale Rand gelegen, die sogenannte Rosette. Die Gelenkflächen der Radialia (Fig. 8) lassen eine Anzahl Gruben erkennen, von denen die zunächst ventralgelegenen Muskelgruben sind. Sie haben annähernd dieselbe Grösse, wie die durch eine schräge Leiste von ihnen getrennten Ligamentgruben und besitzen eine glatte Oberfläche.

Die ambulacrale Täfelung der Pinnula (Taf. 2, Fig. 19, Taf. 3, Fig. 23) besteht aus Seitenplatten und Deckschuppen. Die Deckschuppen sind ganzrandige, feinmaschige, annähernd ovale Blättchen; sie ruhen auf den Seitenplatten und sind wahrscheinlich beweglich, da ihre Stellung eine sehr wechselnde ist. Bald liegen sie dachziegelartig flach übereinander, bald sind sie mehr aufgerichtet; betrachtet man sie in dieser Lage von unten, so sieht man, dass sie eine alternirend schräge Stellung zur Längsaxe der Pinnula haben. Ihre genaue Befestigungsart zu bestimmen ist mir einstweilen nicht gelungen. Die Elemente sind äusserst klein, sehr zerbrechlich und schwer zu isoliren. Sie werden durch Weichtheile festgehalten, die selbst nach mehrere Minuten langen Kochen in Kalilauge nicht zerstört werden. Allzu langes Kochen in Kalilauge vertragen, die sehr dünnen zerbrechlichen Plättchen andrerseits auch nicht. Bezüglich der Seitenplatten sei bemerkt, dass sie im Zickzack stehen. Sie bilden so auf jeder Seite der Ambulacralrinne eine Art spanischer Wand. In den Nischen mehr oder minder verborgen, liegen die Sacculi. Die vorspringenden Ecken werden meist von 2 aneinander stossende Platten gebildet (Fig. 19 und 23 se, se'); an anderen Stellen, so namentlich am Ende einer Pinnula, macht es aber den Eindruck, als ob sie von der Abknickung oder Biegung ein und derselben Platten herrührten. — Die Seitenplatten sind weitmaschiger als die Deckplatten, oft von annähernd viereckiger Gestalt und ausgezackten Rändern. An einigen Stellen sieht man (Taf. 2, Fig. 19), dass durch diese regelmässig wiederkehrenden Auszackungen 2 Lücken in der Berührung der Kanten entstehen. Die oberen dieser Lücken (Fig. 19 s.) werden durch die Sacculi ausgefüllt, durch die unteren (Fig. 19 t.) treten die Tentakel nach aussen.

Die beschriebene Species *Antedon agassizii* n. sp. ist, wie wir gesehen haben, dimorphisch, d. h. sie kommt nicht nur in 10-armigen Exemplaren vor sondern auch nicht selten in solchen, die 11 oder 12, ja vielleicht nochmehr Arme besitzen und diese Exemplare würden, da sie 2 Distichalia haben, zu einer ganz andern Serie der *Carpenter*schen Eintheilung gehören, nämlich in die *Spinifera Gruppe.* Da *Antedon agassizii* darin nicht vereinzelt dasteht, sondern innerhalb derselben Gruppen *Antedon flexilis*, *duplex*, *lusitanica* sich ganz gleich verhalten, ebenso *Antedon multispina*, nur mit dem Unterschiede, dass sie auf Grund ihrer 3 Distichalia zum Theil in einer noch andern Serie figurirt, so wirft sich hier naturgemäss die Frage auf, ob eine Eintheilung, die derartige Doppelplacirungen nothwendig machte, natürlich und practisch war. Unserer Auffassung nach hat *Carpenter* in der Zusammenfassung der 10-armigen Antedons zu einer Serie einen entschiedenen Fehler gemacht. Er hat Arten ohne alle sonstige Gemeinschaft miteinander darin vereinigt wie z. B. die äusserst verschiedenen Arten der Basicurva und Tenella Gruppe, während er andre die durch den Besitz einer ambulacralen Bewaffnung, durch ihre horizontale und bathymetrische Verbreitung im Gegensatz zu den übrigen Species stehen, weit voneinander trennte. Auch unter den Arten mit unbedeckten Ambulacren finden sich solche die bald 10-armig, bald mehrarmig erscheinen; auch sie bestätigen, dass der Character der 10-Armigkeit kein zuverlässiger ist und deshalb nicht hätte Veranlassung geben dürfen übrigens soweit verschiedene Species in einer Serie systematisch zu verbinden. Jeden, der sich mit Comatuliden beschäftigt hat, muss der übereinstimmende Charakter im Habitus der Basicurva, Spinifera und Granulifera Gruppe frappirt haben, dazu kommt, dass sie viele Tiefseeformen aus dem pacifischen Ocean und dem Caraibischen Meere enthalten, während die grosse Mehrzahl der übrigen flacheren Gewässern angehören und indischen Ursprungs sind. (So vor Allem die zahlreichen Arten der Savignyi und Palmata Gruppe.[1]) Unsre Ansicht geht also dahin jene 3 Gruppen und die *Elegans Gruppe*, bei welcher die äusseren beiden Radialia im Gegensatz zu allen andern Antedon Arten durch Syzygie verbunden sind, bei welchen aber die Scheibe und die Ambulacralia innerhalb der äussersten Axillaria getäfelt sind, zu einer grossen Serie zu vereinigen und sie einer zweiten Serie gegenüber zu stellen, welche die Gruppen mit ungetäfelten Ambulacren umfasst. Es stellt sich das übersichtlich folgendermaassen dar.

I. Arten mit getäfelten Ambulacren: Serie I.

a) Die 2 äusseren Radialia durch Gelenk verbunden.

| | | |
|---|---|---|
| 10 Arme | Basicurva | Gruppe. |
| | Acœla | " |
| 2 Distichalia | Spinifera | " |
| 3 Distichalia | Granulifera | " |

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[1] *Hartlaub, A.*, Beitrag zur Kenntniss der Comatulidenfauna des Indischen Archipels in: Nova Acta Leopold Car. Akad. Bd. LVIII. Nr. 1. 1891. 4o.

b) Die 2 äusseren Radialia
durch Syzygie verbunden    Elegans Gruppe.

II. Arten mit ungetäfelten Ambulacren: Serie II.

| | |
|---|---|
| 10 Arme | Eschrichti Gruppe.<br>Milberti "<br>Tenella " |
| 2 Distichalia | Palmata " |
| 3 Distichalia | Savignyi " |

## II. ARTEN OHNE AMBULACRALE TÄFELUNG.

### **ESCHRICHTI GRUPPE** Carp. Chall. Rep. XXVI. p. 136.

"10 Arme. Die ersten zwei oder drei Pinnula Paare lang und geisselförmig, mit zahlreichen kurzen und breiten Gliedern."

*Uebersicht und Verbreitung der Arten:* —

Zahl der bekannten Arten: 9.

Bathymetrische Verbreitung, 20–782 Faden.

In Tiefen unter und bis 200 Faden:

| | | | |
|---|---|---|---|
| 20–632 | Faden, | Le Have Bank. | *Antedon Eschrichti* Müll. |
| 25–410 | " | Smith Sound. | " *quadrata* Carp. |
| 30 | " | Magellan Str. | " *magellanica* Carp. |
| 75 | " | Südsee. | " *antarctica* Carp. |
| 132 | " | Kara See. | " *barentsi* Carp. |
| 150 | " | Südsee. | " *australis* Carp. |

In Tiefen über 200 Faden:

| | | | |
|---|---|---|---|
| 20–632 | Faden, | Porcupine Sta. 57. | *Antedon eschrichti* Carp. |
| 25–410 | " | Davis Str. | " *quadrata* Carp. |
| 286 | " | Bucht v. Panama. | " *tanneri* Hartl. |
| 676–782 | " | bei Mariato Point. | " *rhomboidea* Carp. |

Die höchste bis jetzt für die Gruppe nachgewiesene *Bodentemperatur* war 35,2 F. (= 1,67 Celsius) [*A. australis* zw. Heard Island und Kerguelen]. Auf Station 286 des Albatross aber — dem Fundort der neuen Art *A. tanneri* betrug die Bodentemperatur 45,9 F. (= 7,70 Celsius).

### Antedon rhomboidea Carp.[1])

**Taf. I. Fig. 1, 2, 3, 6, 10, 11; Taf. II. Fig. 12, 14, 15, 17.; Taf. III. Fig. 24.**

Centrodorsale flach kuppelförmig, mit einer cirrusfreien Aushöhlung im Scheitel; circa 60 Cirren in 4–5 Reihen. Cirren gleichmässig dünn, mit etwa 40 Gliedern, die vom 4. bis etwa 10. langgestreckt sind und bis gegen das 20. Glied noch länger wie breit bleiben. Die Cirren sind mit Ausnahme der 7 oder 8 untersten Glieder stark comprimirt. Von der dorsalen oder ventralen Kante betrachtet, erscheinen daher auch die äusseren Glieder noch länglich. Das dorsale Profil der distalen Hälfte des Cirrus erscheint gezackt weil auf dieser Seite die Enden der Glieder vorspringen und selbst die Form kleiner Dornen annehmen. Die Länge der Cirren erreicht zuweilen 6 cm.

*Erste Radiale* kurz; zweite sehr kurz, seitlich nicht in Berührung unter einander, auf ihrer Verbindung mit dem Axillare eine starke knopfartige Erhebung, die an jüngeren Exemplaren aber kaum angedeutet ist. Axillare ziemlich gross, dreieckig; seine proximale Seite ist bedeutend breiter als die daran stossende distale Kante des 2. Brachiale.

10 *Arme*, die in ihrer proximalen Hälfte ziemlich dick und glatt sind und überall rundliche Glieder haben. Erste Brachialia kurz, auf der Innenseite mit einander nicht in Berührung; auf ihrer Verbindung mit dem zweiten ein starker Knopf; ähnliche knopfartige Erhebungen von schwächerer Entwickelung bemerkt man alternirend seitlich gelegen bis zum 10. oder 11. Gliede. Zweites Brachiale annähernd dreieckig. 3. Brachiale quadratisch (Syzygie); folgende Glieder bis zum 8. (2. Syzygie) von fast derselben Länge aber mehr trapezförmig. Auf das 8. folgen 2 oder 3 kürzere, scheibenförmige Glieder und auf diese ausgesprochen dreieckige. In der äusseren Armhälfte, wo die Glieder feindornige, verdickte überragende Distalränder bekommen, wird die Gliedform wieder mehr trapezoid.

*Erste Syzygie* im 3. Brachiale, zweite im 8., dritte Syzygie im 13. oder 14. Gliede, seltner schon im 12. oder erst im 15. Dann in Zwischenräumen von 2–3 Gliedern.

*Erste Pinnula* (Br. 2) lang und dünn geisselförmig, mit etwa 50 ausschliesslich kurzen Gliedern; 18 mm. lang; zweite etwas länger und von fast gleicher Form; ihre Glieder sind etwas dicker und meist länglich. Dritte Pinnula kürzer, mit viel weniger, aber bedeutend verlängerten Gliedern; vierte am kürzersten. Die Pinnulæ bleiben am ganzen Arm dünn und ihre Glieder, mit Ausnahme der 2 basalen, stark verlängert. Länge einer Pinnula am circa 59. Armgliede 25 mm.

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[1]) Chall. Rep. XXVI. p. 148. Pl. XII. Fig. 1 & 2; Pl. XXIV. Fig. 1–3.

*Sacculi*, spärlich.

*Färbung*, hellbräunlich.

*Scheibe*, etwa 12 mm.

*Klafterung*, wenigstens 31 cm. (Exemplar St. 3357), 28–29 cm. Ex. St. 3424.

*Fundorte*, St. 3357, in der Nähe von Mariato Point, 782 Faden Tiefe, Moderner Grünsand, Bodentemperatur 38.5 F.; und St. 3424, 676 Faden, bei Las Tres Marias, grüner Sand, Globigerinen, Bodentemperatur 38,04 F.

Die obige Beschreibung ist, mit Ausnahme der untersten Pinnulæ, welche zu verstümmelt waren, und mit Ausnahme der Cirren, die leider ganz fehlten, auf das Exemplar von St. 3357 zu beziehen (Taf. 2, Fig. 15). Die Beschreibung der Cirren und Pinnulæ aber wurde nach den Exemplaren von Las Tres Marias entworfen.

Ich habe die obige Schilderung der Art, die ich schrieb im Glauben, dass die vorliegenden Exemplare einer neuen Species angehörten, hier gegeben, weil sie von *Carpenters* Beschreibung und namentlich von seiner Abbildung, Chall. Rep. XXVI. Pl. 12, in vielen Puncten abweicht. Auf *Carpenters* Abbildung ist das Centrodorsale ventral durch eine scharfe grade Linie begrenzt; von den ersten Radialien sind nur die Ecken sichtbar, die zweiten Radialia scheinen sich seitlich zu berühren; sie sowohl wie die ersten Brachialia sind in Uebereinstimmung mit der Beschreibung l. c. p. 148 "deeply incised." Alles das verhielt sich an meinen Exemplaren anders und veranlasste mich zunächst zu einer specifischen Abtrennung. Nachdem ich aber vor Kurzem vom Hamburger Museum ein von *Dr. Rehberg* in der Magellhan Strasse (Smyth's Channel) gesammeltes Exemplar von *Antedon rhomboidea* selbst untersucht habe, bin ich ganz andrer Meinung geworden. Ich glaube, dass die vermeintlichen Unterschiede nur auf Ungenauigkeiten der von *Carpenter* gegebenen Figur beruhen. Das Hamburger Exemplar von *A. rhomboidea* stimmt in jeder Hinsicht mit denen vom Albatross gesammelten. Die Art kommt also sowohl in der Magellhan Strasse als an der pacifischen Seite Central Americas vor. "A similar extensive geographical range from north to south has been observed in the distribution of some of the Mollusks Echini and Starfishes, which extend all the way from the southern extremity of South America to the Panamic region. The course of the northerly current setting along the west coast of South America must of course act as a distributer of the marine fauna of that region" (A. Agassiz, Bull. Mus. Comp. Zool., XXIII. No. 1, p. 75).

Die Exemplare von Las Tres Marias unterscheiden sich nicht unbeträchtlich von dem Exemplar der St. 3357. Hierfür ist vielleicht maassgebend, dass sie aus sehr verschiedenen Tiefen stammen. Die Las Tres Marias Exemplare haben vor Allem einen viel schlankeren gracileren Habitus und erinnern in ihrer Erscheinung mit ihren dicht zusammengelegten, meist gestreckten Armen an eine *Antedon phalangium,* wie sie *Carpenter* (l. c. Taf. XXVIII) abgebildet hat. Die Knöpfe der Armbasis und der Radialien sind nur schwach entwickelt und die alternirend seitlich gelegenen in der unteren Armgegend fehlen ganz. Die Armglieder, namentlich die syzygialen, sind gestreckter.

Die Abbildungen Taf. 1, Fig. 1–3, 6, 10 und 11 geben ein Bild vom Calyx und seinen einzelnen Theilen. Fig. 1 zeigt das radiale Pentagon von der Dorsalseite. Weder von einem Basalstern noch von einer Rosette sind irgend welche Spuren zu bemerken. Die dorsale Oeffnung des Trichters ist weit (Fig, 1), und der Hohlraum im Centrodorsale (Fig. 2 h) dementsprechend. Die Gelenkflächen der Radialia (Taf. 1, Fig. 3 und 10) zeigen im Gegensatz zu *Antedon eschrichti* (Chall. Rep. XXVI. Pl. 1, Fig. 8a) eine gleichmässige Neigung gegen die verticale Hauptaxe; ihr ventraler Rand ist in der Mitte ziemlich stark eingeschnitten; von diesem Einschnitt verläuft eine Verticalleiste gegen das Loch des Centralcanals zu. Die Muskelgruben sind grösser als die Ligamentgruben und von ihnen durch eine ziemlich horizontal gerichtete Querleiste geschieden, die mit 2 mehr oder minder deutlich ausgeprägten Wurzeln entspringt, deren eine von der Verticalleiste, die andre an der Seite des Centralcanals ihren Ursprung nimmt. Auf der Fläche der Muskelgruben bemerkt man schwache, gebogene Querfurchen. Fig. 6 zeigt die ventrale Oeffnung des Trichters und die kleinen in denselben vorspringenden Zacken, die etwas unterhalb des Randes liegen und ventrale Enden von Längsleisten sind, die sich auf der Trichterfläche der Radialia befinden (Taf. 1, Fig. 11). — Diese Verhältnisse wurden an einem älteren und einem viel jüngeren Exemplare von Las Tres Marias untersucht und übereinstimmend gefunden.

*Carpenter* bildet im Chall. Rep. die besprochenen Theile für *Antedon eschrichti* und *antarctica* ab. Von diesen zeigt *Antedon eschrichti* die meiste Uebereinstimmung mit unsrer Art. Wir finden auch bei ihm auf der ventralen Kante der Radialia den medianen Einschnitt, und scheint es, dass derselbe innerhalb der Gruppe allgemeiner vorkommt, da er noch viel stärker entwickelt ist an der neuen Species, die uns sogleich beschäftigen wird. *Antedon eschrichti* besitzt ferner Querfurchen in den Muskelgruben, aber was ihn wesentlich unterscheidet, ist der Besitz einer Rosette, von der ich bei *Antedon rhomboidea* nichts bemerkte.

An vielen Exemplaren sassen cystenbildende Myzostomen.

## **Antedon tanneri** n. sp.

**Taf. I. Fig. 9; Taf. II. Fig. 13; Taf. III. Fig. 20, 22.**

*Centrodorsale* flach gewölbt, mit einer cirrusfreien Grube im Scheitel. Etwa 60 dichtstehende, gleichmässig dünne, comprimirte Cirren, die eine Länge von 33 mm. erreichen. Die Cirren haben grössten Theils längliche Glieder; die letzten davon sind kürzer und haben manchmal einen endständigen kleinen Dorn auf der dorsalen Seite.

*Erste Radialia* sichtbar, kurz. Zweite kurz und sich distalwärts verschmälernd, nicht in Berührung untereinander. Axillare rhombisch, am Ansatz der Arme beträchtlich verbreitert.

10 *Arme*, die sehr schlank und dünn sind und von Anfang an eine ganz unebene Oberfläche besitzen. Erste Brachialia von einander getrennt, kurz; zweite von unregelmässiger Form und von etwa doppelter Länge; drittes Glied (Syzygie) noch länger. Die folgenden bis zum 7. sind annähernd quadratisch und haben stark eingebogene Flächen. Das 8. Glied hat die Länge des dritten. Das erste und zweite Brachiale haben bisweilen einen kleinen seitlichen Dorn, der bei lezterem dicht vor dem Ansatz seiner Pinnula liegt. Auf das Glied der zweiten Syzygie folgen noch etwa 3 quadratische Glieder, dann wird die Form mehr trapezoid (aber nirgends dreieckig!). Die Glieder verbreitern sich alle etwas distalwärts, und ihre, in der zweiten Armhälfte etwas dornigen, Ränder überragen stark die Basis der nachfolgenden Glieder, was eine grosse Rauhigkeit der Armoberfläche zur Folge hat. Die Arme sind an ihrer Basis rundlich und weiterhin mehr comprimirt; sie verdünnen sich bis etwa zum 15.–20. Gliede rasch und nachher ganz allmälig.

*Erste Syzygie* im 3. Brachiale, zweite im 8., dritte im 14., die folgenden in Zwischenräumen von 2–3 Gliedern.

*Pinnula* des zweiten Brachiale 14–16 mm. lang mit 35–44 kurzen Gliedern, geisselförmig und in eine sehr feine Spitze auslaufend. Am Ende der Pinnula ist eine Art Kamm entwickelt (Taf. 2, Fig. 13). Pinnula des 4. Brachialia manchmal etwas länger sonst ebenso. Dritte Pinnula bedeutend kürzer als die zweite und aus einer viel geringeren Zahl länglicher Glieder zusammengesetzt; ohne Kamm am Ende. Vierte Pinnula ebenso lang, dann nimmt die Länge ganz allmälig ab. Die 14 Pinnula ist etwa 10 mm. lang, doch sind die der äusseren Armhälfte wieder einige mm. länger. Alle diese Pinnulæ sind sehr dünn und haben, mit Ausnahme der zwei basalen, stark verlängerte Glieder.

*Scheibe* etwa 7 mm. Dm., mit zerstreuten Kalkkörperchen. — Mund central.

*Sacculi* zahlreich an den Ambulacren der Pinnulæ, Arme und Scheibe.

*Klafterung* durchschnittlich 20 mm.

*Färbung*, in Alcohol, hell gelblich; Pinnulæ bräunlich.

*Fundort*, St. 3385, Eingang der Bucht von Panama, 286 Faden, grüner Mud; Bodentemperatur 45,9 F. Zahlreiche Exemplare.

In einiger Hinsicht gleicht diese, neue Art vollkommen der vorigen, so besonders in der Form ihres Centrodorsale und ihrer Cirren, doch lässt ihr ganz anderer Habitus, die grosse Rauhigkeit ihrer Armoberflächen und die Verschiedenheit der radialen Gelenkfläche, die ich an 2 Exemplaren untersuchte, wohl keinen Zweifel an ihrer Berechtigung zu. Bezüglich der Gelenkflächen vergleiche man die Figuren 9 und 10 auf Tafel 1. Wir finden bei unsrer Art an Stelle einer verticalen Längsleiste, eine breite flache intermuskulare Mulde. Solch eine Bildung ist charakteristisch für die Gattung *Actinometra*, bei *Antedon* aber sehr selten (*Antedon disciformis* Palmata Gruppe). Sie gewinnt für unsre Art an Interesse, wenn man bedenkt, dass auch die unteren Pinnulæ durch den Besitz eines Kammes ein *Actinometra* ähnliches Verhalten zeigen. Von den radialen Gelenkflächen wäre weiterhin der ungemein tiefe Einschnitt ihres ventralen Randes zu erwähnen. Zu beiden Seiten dieses Einschnittes liegen die Muskelgruben auf leicht nach aussen gekrümmten Fortsätzen, die in ihrer Form langen Ohren gleichen. Sie haben leicht angedeutete, gebogene Querleisten. Von den Ligamentgruben sind sie durch sehr schwache Leisten getrennt, die ihren Ursprung seitlich vom Centralcanal nehmen, anfänglich vertical verlaufen und dann in einem ziemlich scharfen Winkel schräg nach oben abbiegen.

Das starke Ueberragen der Armglieder (overlapping of the armjoints), was unsrer neuen Art ein so eigenes Gepräge verleiht, theilt sie in der Eschrichti Gruppe mit *Antedon antarctica* Carp.

An Zierlichkeit des Wachsthums wird sie wohl von Keiner der verwandten Formen erreicht.

An sehr vielen Exemplaren fand ich cystenbildende Myzostomen.

## **TENELLA GRUPPE** Carp. Chall. Rep. XXVI. p. 156.

"10 Arme. Die Glieder der untersten Pinnulæ, welche oft lang und schlank sind, sind länger wie breit und dies oft in hohem Grade."

Die von *Carpenter* in der Tenella Gruppe zusammengefassten Arten, einige zwanzig an der Zahl, haben ausserordentlich weite Grenzen sowohl in ihrer horizontalen als in ihrer bathymetrischen Verbreitung. Es sind unter ihnen zwei (*Antedon hirsuta* und *exigua*) vom 46. Grade südlicher Breite und eine (*Antedon prolixa*) vom etwa 70. Grade nördlicher Breite. Nur sehr wenige Antedon Arten überschreiten überhaupt diese Breiten. Andrerseits ist die Hauptmenge der bekannten Species atlantisch, fünf aber gehören dem westl. Pacific an und eine Art (*Antedon nana*) dem indischen Archipel (Amboina). Die Arten, welche ich hier zu beschreiben habe, sind die ersten aus dem östlichen Theile des Stillen Oceans. Bathymetrisch gehören zur Tenella Gruppe sowohl littorale Species wie z. B. *Antedon nana* Hartl. und die europäische *Antedon rosacea*, als auch *Antedon abyssicola* aus 2900 Faden, der grössten Tiefe, aus der überhaupt Comatuliden gefischt wurden. Die neue Art *Antedon parvula* zeigt viel Aehnlichkeit mit der ebenfalls pacifischen *Antedon alternata* (south of Japan, northeast of New Zealand, Kermadecs, north of Papua) während *Antedon bigradata* n. sp. näher mit der oben erwähnten *Antedon prolixa* von Faeroe Channel und Smith Sound, Kara See, verwandt ist. Wie die übrigen pacifischen Arten, so wurden auch die vom Albatross gefischten in grossen Tiefen gefangen nämlich *Antedon parvula* in 978 Faden und *Antedon bigradata* in 385 und in 555 Faden. Ausser diesen beiden Species erhielt der

Albatross noch stark verstümmelte Exemplare von zwei andern Arten, von denen das eine, wahrscheinlich *Antedon abyssicola,* bei St. 3381 aus der bedeutenden Tiefe von 1772 Faden gefischt wurde.

### **Antedon parvula** n. sp.

**Taf. III. Fig. 21.**

*Centrodorsale* annähernd conisch mit schwacher Wölbung nach aussen. 20–30 Cirren, von 5–6 mm. Länge, deren Gliederzahl etwa 20 beträgt. Das 3., 4. und 5. Glied sind stark verlängert. Die folgenden werden schnell kürzer; die langen Glieder sind in der Mitte eingeschnürt. Die distalen Ränder sämmtlicher Glieder springen vor, und die dorsale Contur des Cirrus ist stark gezackt. Das Ende des Cirrus ist etwas comprimirt.

*Erstes Radiale* etwas kürzer als das zweite und mit leicht eingebogenem distalem Rande; seitlich frei. Zweite kurz, nicht eingeschnitten, ebenfalls seitlich frei. Axillare rhombisch.

10 *Arme.* Erste Brachialia kurz, scheibenförmig, untereinander nicht in Berührung. Zweite fast doppelt so lang, von etwas wechselnder Form (bald mehr dreieckig, bald mehr viereckig). Drittes Brachiale (Syzygie) noch länger; jedes seiner syzygialen Glieder reichlich so lang wie das erste Brachiale. Es folgen vier fast quadratische Glieder und darauf das 8. (Syzygie), das wieder länger ist; dann ausschliesslich trapezoide Glieder, die bald die definitive, nicht unbedeutende Länge erreichen. (Das Armende ist an keinem Arm erhalten.)

*Syzygien* im 3., 8., 12. und darauf in Unterbrechungen von einem Gliede.

*Pinnula* des 2. Brachiale sehr dünn; die Glieder sind in der Mitte und gegen das Ende der Pinnula zu ziemlich stark verlängert, und haben vorspringende, fein gezähnte distale Ränder. (Keine war vollständig, eine aber bis zu 15 Gliedern erhalten). Die folgende Pinnula (Br. 6) 6 mm. lang mit circa 15 Gliedern, die der Mehrzahl noch stark verlängert sind. Pinnula des 6. Brachiale kürzer und aus etwa 10 stark verlängerten Gliedern bestehend. Die Pinnula des 8. Brachiale scheint die kürzeste zu sein. Die Glieder sämmtlicher folgenden Pinnulæ sind stark verlängert.

*Scheibe* nicht sichtbar (auf etwa 3 mm. Dm. zu schützen).

*Färbung* weisslich.

*Klafterung* auf 60 mm. zu schützen.

*Sacculi* nicht deutlich zu erkennen.

*Fundort*, St. 3363, 978 Faden, Cocos Islands, weisser Globigerinen Schlamm; Bodentemperatur 37,5 F. Ein Exemplar.

Das winzige Exemplar, welches obiger Beschreibung zu Grunde liegt, trenne ich trotz übrigens grosser Aehnlichkeit mit *Antedon alternata* Carp. vorläufig von dieser specifisch ab, weil sich seine Cirren sehr wesentlich von denen jener unterscheiden (Taf. III, Fig. 21, und Chall. Rep. Pl. 22, Fig. 8 & 9). Ich kann aber nicht läugnen, dass mir trotzdem diese neue Art einiges Bedenken macht. Gewisse Uebereinstimmungen, so vor Allem solche in der Form des Centrodorsale, in der Form der Radialia, in der abwechselnden, ein Glied überspringenden Lage der Syzygieen, sind auffallend genug.

## **Antedon bigradata** n. sp.

**Taf. I. Fig. 5.**

*Centrodorsale* ziemlich lang conisch, mit abgestumpfter Spitze und etwas gewölbten Seiten. Die Cirrusgruben sind tief (Cirren selbst sind nicht erhalten), etwa 80 an der Zahl und stehen in 5 Feldern, die durch schmale interradiale Zwischenstreifen getrennt sind. Innerhalb der Felder stehen die Cirrusgruben in 4 verticalen Reihen, jede Reihe mit 4 Gruben. Die einzelnen Gruben berühren sich nicht untereinander.

Zwischen Centrodorsale und jedem ersten Radiale befindet sich eine spaltartige Vertiefung. Erste Radialia sichtbar und zwar nicht bloss an den Ecken des Calyx (wie die *A. hystrix*). Zweite Radiale kurz; es steht senkrecht zur Hauptaxe und im rechten Winkel zum Axillare; ebenso steht das erste Brachiale zum zweiten Brachiale. Kelch und Armbasis erscheinen durch diese Stellungsweise auffallend getreppt. Das radiale Axillare ist viereckig, sein proximaler Winkel spitz und lang ausgezogen; die beiden Seitenwinkel nach vorn gerückt.

*Erste Brachiale* kurz und dorsal kürzer als ventral. Zweite Brachiale dreieckig, drittes ziemlich kurz, dann 4 ebenfalls ziemlich kurze trapezoide Glieder, die auf ihrer pinnulatragenden Seite etwa halb so kurz sind als auf der andern.

Die *Pinnula* des zweiten Brachiale hat etwa 13 Glieder, von denen schon das erste bedeutend länger als dick ist, das zweite aber schon mindestens 2 mm. lang ist. Die Pinnula des 3. Brachiale ist klein und hat ebenfalls ein längliches Basalglied. Pinnula des 4. Brachiale kürzer wie die des 2. mit 9 Gliedern, von denen das Basale ebenfalls länglich ist. An der Pinnula des 6. Brachiale, die aus etwa 9 Gliedern besteht, sind die zwei basalen Glieder kaum noch länger wie breit und auch die folgenden Glieder etwas kürzer.

*Scheibe* des Exemplars von St. 3404 hat 12 mm. Dm.

*Färbung,* hell röthlich braun mit weissen Flecken auf den Verbindungen der Pinnula Glieder.

*Fundorte,* St. 3358, 555 Faden, in der Nähe von Cap Mariato Point, "Modern Greensand," Bodentemperatur 40,2 F.; St. 3404, 385 Faden, zwischen Chatham und Hood Island, felsiger Grund, Bodentemperatur 43,2 F.

Die neue Art ist nahe verwandt mit *Antedon prolixa* Sladen, und mit dieser ist, wie mir *Carpenter* brieflich mittheilte, *Antedon hystrix* identisch. Da mir die *Sladen*sche Beschreibung von *A. prolixa* nicht zugänglich ist, beschränke ich mich darauf auf die Unterschiede hinzuweisen, welche die neue Art im Vergleich mit *Carpenters* Beschreibung von *A. hystrix* darbietet. Besonders ist da hervorzuheben, dass die Cirren von *A. bigradata* in 5 Feldern stehen und innerhalb dieser wieder in Verticalreihen; sodann ist die spaltartige Vertiefung zwischen jedem ersten Radiale und dem Centrodorsale bemerkenswerth. Mehr Gewicht aber ist wohl noch auf die Verschiedenheit zu legen, welche die Pinnula des 2. Brachiale im Vergleich mit der von *A. hystrix* zeigt. Während sie nämlich bei letzterer 15 mm. lang ist und einige 30 Glieder hat "the first six of which are short and nearly square," hat sie bei unserer neuen Art 13 Glieder, von denen schon das erste bedeutend länger als dick ist.

## Antedon spec.

**Taf. IV. Fig. 25.**

*Fundort,* St. 3381, 1772 fath., Golf von Panama, in der Nähe von Malpelo Island, "Green Mud," Bodentemperatur 37,2 F. Ein Exemplar.

Am vorliegenden Exemplar fehlen die Cirren, und die Arme sind vom 3. Brachiale ab abgebrochen. Von den untersten Pinnulæ sind nur stellenweise einige Glieder erhalten.

Es handelt sich wahrscheinlich um *Antedon abyssicola* oder eine dieser sehr nahe verwandten Art.

Das Centrodorsale ist conisch und trägt etwa 25 Cirrusgruben, die relativ gross sind und dicht aneinander stehen. (*Antedon abyssicola* hat nach Carpenter 15 Cirren). Die ersten Radialia sind wie bei *A. abyssicola* vollkommen sichtbar. Die Ecken schieben sich ein wenig zwischen die zweiten Radialia ein, sodass diese nicht seitlich in Berührung stehen. Dasselbe Verhalten zeigt *A. abyssicola* gelegentlich in ausgeprägtem Maasse.

An dem Exemplar sitzt als Schmarotzer festgeheftet ein *Stylifer* verwandte Schneckenart (nach Prof. *v. Martens* wahrscheinlich eine *Mucronalia*).

### Antedon spec.

**Taf. IV. Fig. 27.**

*Fundort*, St. 3354, 322 fath., in der Nähe der Küste bei Mariato Point, "Green Mud," Bodentemperatur 46,0 F. Ein Exemplar.

Eine Bestimmung ist nicht ausführbar, weil die Cirren und untersten Pinnulæ fehlen und die Arme sämmtlich nahe ihrer Basis abgebrochen sind. Die conische Form des Centrodorsale, die bedeutende Zahl der Cirrusgruben sowie die Form der Radialia und untersten Armglieder lassen auf eine *Antedon prolixa* nahestehende Art wenn nicht gar auf diese selbst schliessen.

*Uebersicht der vom Albatross gesammelten Arten.*

Gesammtzahl der Species, 7.

Sämmtliche Species gehören dem Genus *Antedon* an und vertheilen sich, wie folgt, auf drei Gruppen: —

## I. BASICURVA GRUPPE Carp.

### Antedon agassizii n. sp.

Fundorte:

St. 3357, 782 Faden, "modern greensand," nicht weit von Mariato Point.
" 3408, 684 " Globig. Ooze. } Galapagos.
" 3409, 327 " "black sand." } Galapagos.

## II. ESCHRICHTI GRUPPE Carp.

### Antedon rhomboidea Carp.

Fundorte:

St. 3357, 782 Faden, "modern greensand," nicht weit von Mariato Point.
" 3424, 676 " "gray sand," Las Tres Marias Inseln.

### Antedon tanneri n. sp.

Fundort:

St. 3385, 286 Faden, "green mud," Golf von Panama.

## III. TENELLA GRUPPE CARP.

### **Antedon spec.**

Fundort:
St. 3354, 322 Faden, "green mud," bei Mariato Point.

### **Antedon bigradata** n. sp.

Fundorte:
St. 3358, 555 Faden, "modern greensand," nicht weit von Mariato Point.
" 3404, 385 " "rocks," Galapagos.

### **Antedon parvula** n. sp.

Fundort:
St. 3363, 978 Faden, "white Glob. Ooze.," Cocos Inseln.

### **Antedon spec.** (abyssicola Carp. ?).

Fundort:
St. 3381, 1772 Faden, "green mud," nicht weit von Malpelo Island.

Besonderes Interesse verdienen des Fundortes wegen die zur *Eschrichti Gruppe* gehörenden Arten.

# ERKLÄRUNG DER ABBILDUNGEN.

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## TAFEL I.

| | | | |
|---|---|---|---|
| Fig. 1. | **Antedon** | **rhomboidea Carp.** | Exemplar von Las Tres Marias. Dorsale Ansicht des radialen Pentagons; vergrössert × 5. |
| Fig. 2. | “ | “ | Ventrale Ansicht des Centrodorsale vom selben Exemplar; vergr. × 5. |
| Fig. 3. | “ | “ | Calyx von der Seite, vom selben Exemplar; vergr. × 5. |
| Fig. 4. | “ | **agassizii n. sp.** | Ventrale Ansicht des Centrodorsale; vergr. × 7. |
| Fig. 5. | “ | **bigradata n. sp.** | vergr. × 3. |
| Fig. 6. | “ | **rhomboidea n. sp.** | Ventrale Ansicht des Calyx; vergr. × 5. |
| Fig. 7. | “ | **agassizii n. sp.** | Dorsale Ansicht des radialen Pentagons vom selben Exemplar wie Fig. 4; vergr. × 7. *r.* Rosette; *b.* ein Strahl des Basalsterns. |
| Fig. 8. | “ | “ | Seitenansicht des Calyx; vergr. × 6. *m.* Muskelgrube; *l.* Ligamentgrube. |
| Fig. 9. | “ | **tanneri n. sp.** | Gelenkfläche des ersten Radiale; vergr. × 15. |
| Fig. 10. | “ | **rhomboidea** | Gelenkfläche des ersten Radiale; vergr. × 11. |
| Fig. 11. | “ | “ | Ansicht eines Radiale vom Trichter aus; vergr. × 6. |

## TAFEL II.

| | | |
|---|---|---|
| Fig. 12. | **Antedon rhomboidea** n. sp. | Pinnula des zweiten Brachiale; vergr. × 4. |
| Fig. 13. | “ **tanneri** n. sp. | Ende der Pinnula des zweiten Brachiale; stark vergr. |
| Fig. 14. | “ **rhomboidea** n. sp. | Theil eines jungen Exemplars von Las Tres Marias; vergr. × 4. |
| Fig. 15. | “ “ | Theil eines Exemplars von St. 3357; vergr. × 2½. |
| Fig. 16. | “ **agassizii** n. sp. | Stück aus der äusseren Armhälfte; vergr. |
| Fig. 17. | “ **rhomboidea** n. sp. | Cirrus eines Exemplars von Las Tres Marias; vergr. × 2. |
| Fig. 18. | “ **agassizii** n. sp. | Proximale Armregion; vergr. |
| Fig. 19. | “ “ | Glied einer Pinnula von der Seite; sehr stark vergr. *se, se′* Seitenplatten; *s.* Platz des Sacculus; *t.* Lücke für den Tentakeldurchtritt; *d.* Deckplatten. |

## TAFEL III.

| | | |
|---|---|---|
| Fig. 20. | **Antedon tanneri** n. sp. | vergr. × 1½. |
| Fig. 21. | “ **parvula** n. sp. | Cirrus; vergr. × 11. |
| Fig. 22. | “ **tanneri** n. sp. | Stück aus der mittleren Armgegend; vergr. × 4. |
| Fig. 23. | “ **agassizii** n. sp. | Glied einer Pinnula; stark vergr. |
| Fig. 24. | “ **rhomboidea**. | Exemplar von Las Tres Marias; vergr. × 1½. |

## TAFEL IV.

| | | |
|---|---|---|
| Fig. 25. | **Antedon** spec. **abyssicola** Carp.? mit einer daran sitzenden **Mucronalia**? | vergr. × 4½. |
| Fig. 26. | **Antedon agassizii** n. sp. | vergr. × 2. *Peters* del. |
| Fig. 27. | “ spec. (Tenella Gruppe). | vergr. 4½. |

*Im Anhang* an die Beschreibung der Albatross Crinoiden möchte ich noch einen ebenfalls dem Mus. of Comp. Zoölogy gehörenden Antedon von *Gaspard Str.* beschreiben, den ich für neu erachte.

## **Antedon subtilis** n. spec. (Palmata Gruppe).

*Centrodorsale* flach scheibenförmig, mit etwa 20 glatten Cirren am Rande, die meist zweireihig stehen. Cirren etwa 12 mm. lang, ziemlich dünn und in der äusseren Hälfte comprimirt. Circa 20 Cirrusglieder, die vom 5. an etwas länglich sind; die äusseren Glieder haben einen ganz schwachen Dorn, das vorletzte einen stärkeren.

Radien vom ersten Radiale an ganz frei seitlich. Erste Radialia seitlich etwas sichtbar. Zweite Radialia kurz, etwas kürzer wie die Seiten des fünfeckigen Radiale axillare. Distichale und palmare Stämme zweigliedrig. Erste Distichale und Palmare etwa so lang wie die Seiten des 2. u. 3. Radiale zusammengenommen. Keine Postpalmaria. Die Glieder der Radialia, Stämme und Arme vollkommen glatt. Nirgends Buckel auf den Verbindungen der Axillaria oder sonstige Protuberanzen.

20 *Arme.* (Ein Radius mit fünf Armen, einer mit drei, die übrigen mit vier). Die Arme sind ziemlich dünn, vollkommen glatt, etwa 5 cm. lang und mit sehr feinen Pinnulæ besetzt; die Armglieder sind kurz und zwar bis zum 8. mehr oder minder scheibenförmig, vom 9. an aber ausgesprochen dreieckig; so bleiben sie bis etwa zum 20. Gliede, von da ab wird die Form mehr trapezoid, und später quadratisch. Das erste Brachiale steht in theilweisem Contact mit dem Nachbargliede.

*Erste Syzygie* im 3. Brachiale, zweite im 14. Brachiale, die dritte nach einen Zwischenraum von 5–6 Gliedern, die folgenden in Zwischenräumen von 6–7.

*Pinnula* des 2. Brachiale etwa 7 mm. lang mit circa 13 glatten Gliedern, die mit Ausnahme der 2 basalen länglich sind. Pinnula des 4. Brachiale beträchtlich stärker und 10 mm. lang, geisselförmig, Glieder wie bei der vorigen länglich mit Ausnahme der zwei ersten. Die darauf folgenden 3 Pinnulæ derselben Armseite ganz winzig, etwa 2 mm. lang. Dann nimmt die Länge allmälig etwas zu, doch bleiben die Pinnulæ des Mittelarms klein und dünn. Die Pinnulæ des Armendes sind von haarartiger Feinheit, aber etwas länger (5 mm.), die Glieder stets länglich.

*Sacculi* dichtstehend.

*Klafterung* etwa 10½ cm.

*Scheibe* tief eingeschnitten.

*Färbung* gleichmässig weiss.

*Fundort*, Gaspar Str. Ein Exemplar.

Die Art ist nahe verwandt der von mir beschriebenen Art *Ant. Klunzingeri* von Koseir aus dem Rothen Meer, unterscheidet sich aber von dieser durch die Kleinheit der Pinnulæ des 6. Brachiale. Dieselbe ist bei *A. Klunzingeri* so lang wie die des ersten Brachiale. Möglicher Weise wird sich nach Untersuchung grösseren Materials herausstellen, dass die beiden Arten identisch sind.

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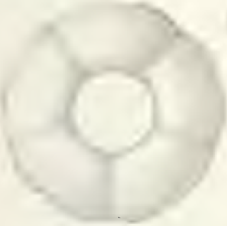

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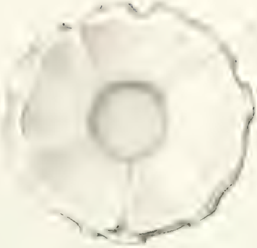

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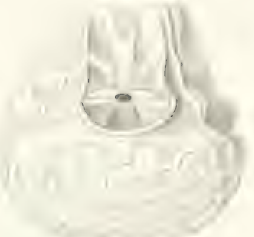

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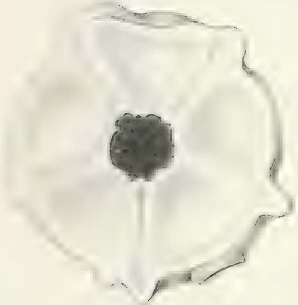

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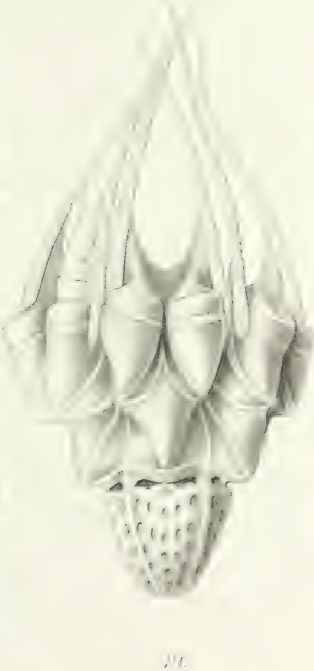

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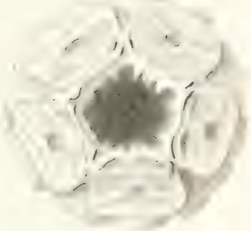

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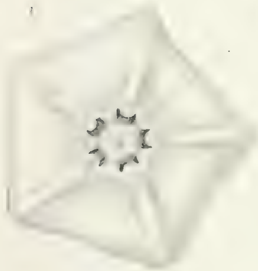

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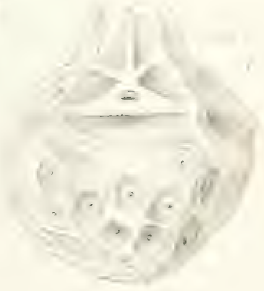

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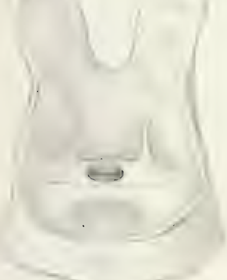

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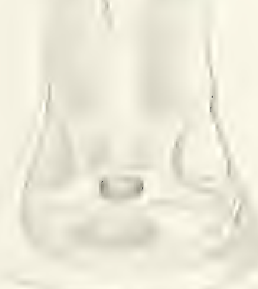

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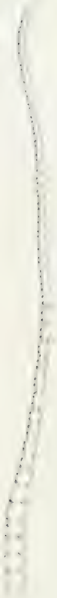

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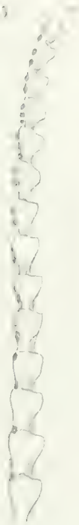

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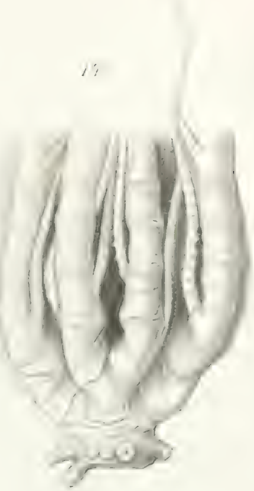

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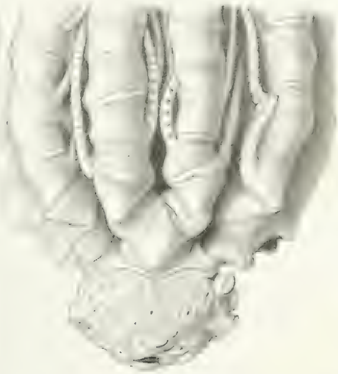

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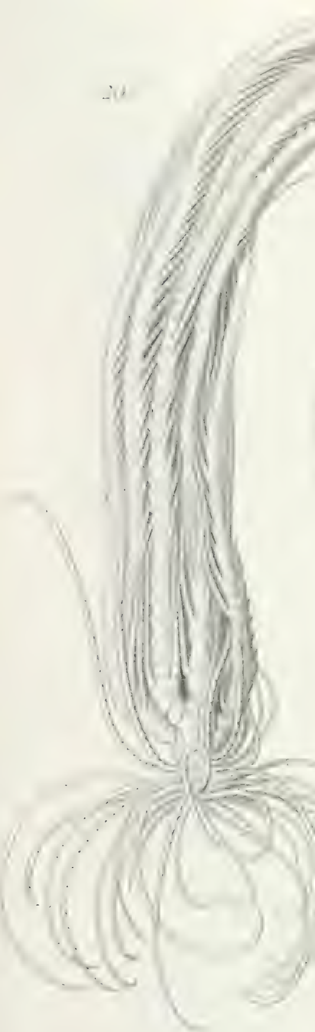

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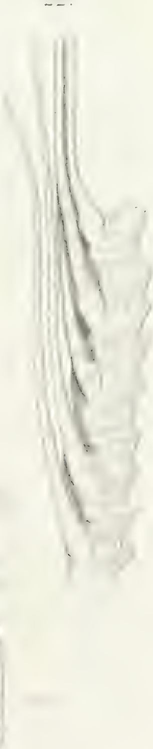

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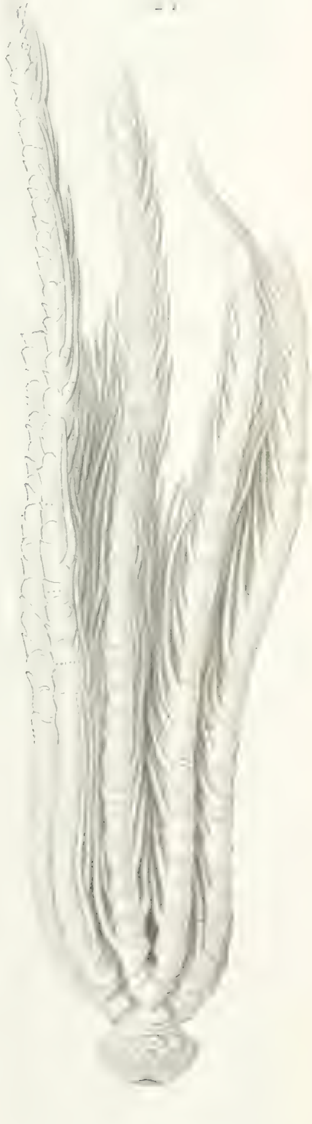

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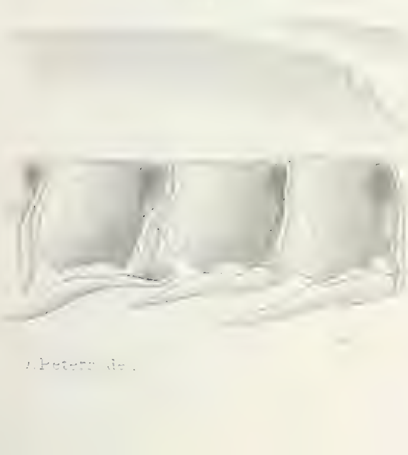

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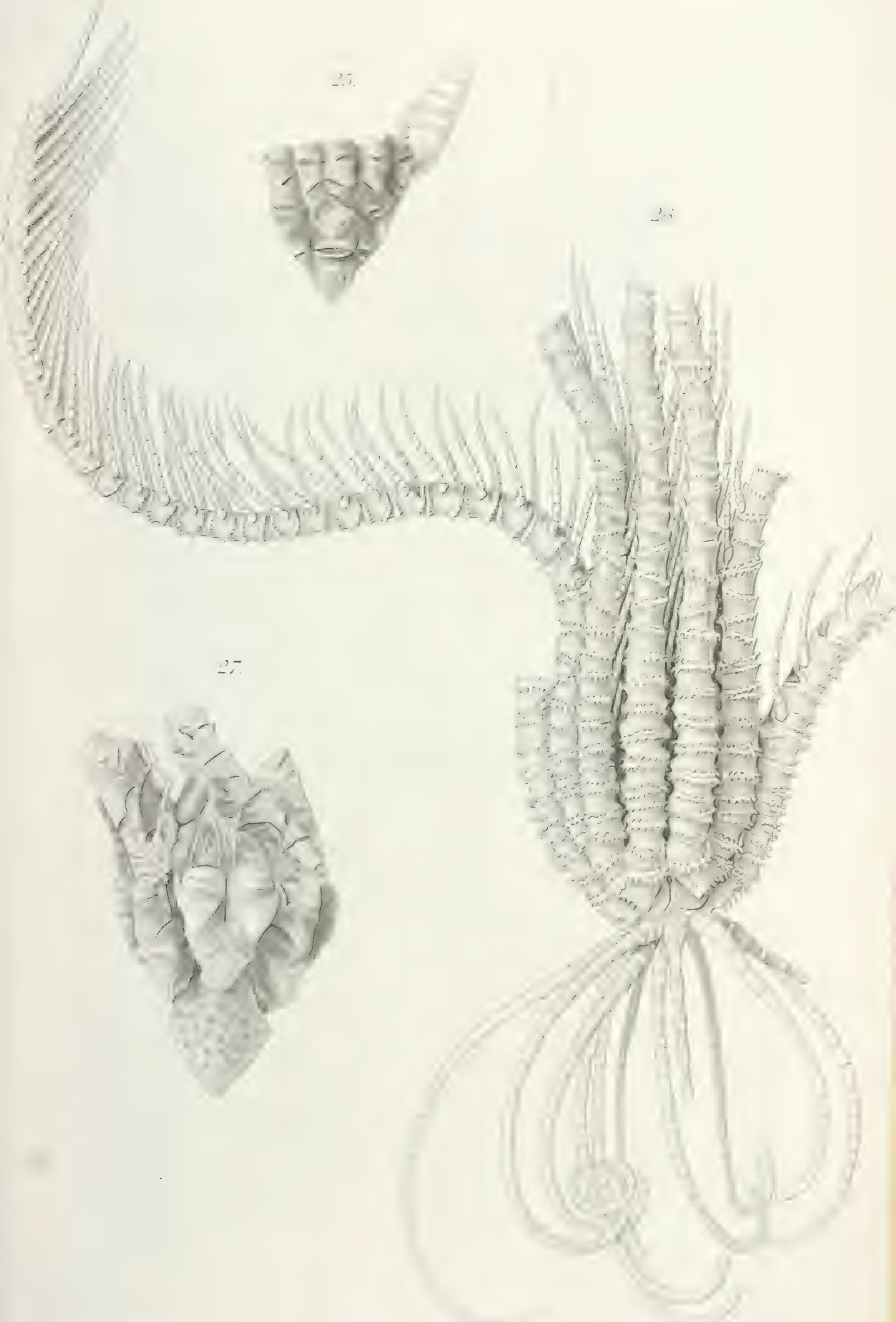

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No. 5. — *Reports on the Dredging Operations off the West Coast of Central America to the Galapagos, to the West Coast of Mexico, and in the Gulf of California, in charge of* ALEXANDER AGASSIZ, *carried on by the U. S. Fish Commission Steamer "Albatross," during* 1891, Lieut.-Commander Z. L. TANNER, U. S. N., Commanding.

[Published by Permission of MARSHALL MCDONALD, U. S. Fish Commissioner.]

## XIX.

## *Die Ostracoden.* Von G. W. MÜLLER.

Die Zahl der gesammelten Arten ist nur gering . zwei Cypridiniden und vier Halocypriden, doch knüpft sich an die beiden Cypridiniden als Vertreter einer neuen Gattung von sehr abweichendem Körperbau und ebenso abweichender Lebensweise ein besonderes Interesse. Es handelt sich, was ich zum Verständniss der folgenden Beschreibung vorausschicke, um Arten von ausschliesslich pelagischer Lebensweise. Ich lege der Besprechung der Cypridiniden, für die ich mit Rücksicht auf ihre auffallende Grösse den Gattungsnamen *Gigantocypris* wähle, die häufigere der beiden Arten, *Gigantocypris Agassizii*, zu Grunde.

Bei einer oberflächlichen Betrachtung kann man in Zweifel sein, ob man es mit einem Ostracoden zu thun hat. Zunächst überrascht die ausserordentliche Grösse, wie sie sonst von lebenden Ostracoden nicht entfernt erreicht wird, wie sie sich auch nur ganz ausnahmsweise bei fossilen findet. Die Thiere erreichen eine Länge von 23 mm. bei eine Höhe von 19.5 und eine Breite von 18 mm. Weiter bietet das Thier das Aussehen einer grossen, dünnwandigen, durchscheinenden Blase mit kurzer, schlitzförmiger Oeffnung, nicht den eines Thieres mit zweiklappiger Schale (Tafel 1, Fig. 1, 2). Eigentlich kann man auch nicht mehr von einer zweiklappigen Schale sprechen. Während sonst bei den Ostracoden die Strecke, für welche beide Schalenhälften mit einander verbunden sind, etwa $\frac{1}{3}$, stets aber weniger als $\frac{1}{2}$ der Peripherie beträgt, beträgt sie hier etwa $\frac{2}{3}$, nur $\frac{1}{3}$ der Schalenränder ist frei. Die freien Ränder der Schale legen sich dicht aneinander, nur am vorderen und hinteren

Ende des Schlitzes weichen sie deutlich auseinander, vorn zur Bildung der bekannten Rostralincisur (Tafel 1, Fig. 1, 2, 6, 8), hinten für eine ovale Oeffnung, welche den anderen Cypridiniden fehlt (Tafel 1, Fig. 1, 2, 7, 9). Innerhalb der übrigen ⅗ der Peripherie, wo beide Schalenhälften fest mit einander verbunden sind, zeigt sich nur in der Nachbarschaft der genannten Oeffnungen eine deutliche Abgrenzung zweier Schalenhälften, sonst markirt sich die Grenze nur als feine, schwer aufzufindende Linie.

Uebrigens ist die Schale sehr dünnhäutig, nur die freien Ränder sind verstärkt. Die Schale ist so dünn und zart, dass fast sämmtliche Thiere, die ich erhielt, sehr stark, auf ¼ oder weniger ihres Volums zusammengedrückt waren, wofür freilich nicht nur die geringe Widerstandsfähigkeit der Schale, sondern auch die geringe Menge fester Substanz, das ausserordentliche Ueberwiegen der Bluträume verantwortlich zu machen ist. Vermuthlich ist dieses Zusammendrücken bereits im Netze erfolgt, die Thiere haben dem Druck des Wassers nicht widerstehen können. Nur 1 Individuum war in seiner Körperform gut erhalten, 1 zweites leidlich, alle übrigen waren stark zusammengedrückt.

Von Verkalkung ist an der Schale durchaus nichts zu bemerken; auch von krystallinischen Concretionen, wie man sie in Folge der Auflösung und Wiederausscheidung des Kalkes in der Schale oder an anderen Körpertheilen bei conservirten Halocypriden und Cypridiniden findet, habe ich nichts entdecken können. Ich glaube danach, dass jede Kalkablagerung fehlt, ein Schluss, der durch das, was ich eben über das Zusammendrücken der Schale sagte, bestätigt wird.

Die Schale ist glatt, entbehrt jeder Skulptur; Haare fehlen so gut wie ganz, nur in der Rostralincisur und in ihrer Nachbarschaft findet sich am Rand ein dichte Reihe kurzer, starker Borsten (Tafel 1, Fig. 8). Das einzige wohl erhaltene Individuum zeigte einen grünlichen Schimmer.

Die innere Schalenlamelle ist noch viel zarter als die äussere, entfernt sich weit von ihr (vergl. Tafel 1, Fig 1 *i. L.*, *a. L.*), so dass der Schalenraum einen sehr umfangreichen Blutraum darstellt. Beide Schalenlamellen sind durch sehr zahlreiche feine Bindegewebsfasern mit einander verbunden, welche die Schale fein und dicht radiär (nach dem Centrum des Körpers hin) gestreift erscheinen lassen (siehe Fig. 1). Der Verlauf des Innenrandes (*Ir.*) in der Nachbarschaft der Rostralincisur ist aus Tafel 1, Fig. 8 ersichtlich. Am Ventralrand zieht er dem Schalenrand parallel, in geringer Entfernung von demselben. Zu einer deutlichen Verschmelzung beider Lamellen kommt es nicht. Der Saum ist schmal, ganzrandig oder fein gesägt, gestreift. In der hinteren Hälfte des Schlitzes zieht eine verstärkte Rippe dem eigentlichen Schalenrand parallel, nach innen von demselben und in seiner nächsten Nähe (Tafel 1, Fig. 7, 9 $R_1$). Kleine einzellige Drüsen sind über die ganze Schale zerstreut; etwas reichlicher entwickelt sind sie am Schalenrand; die Nerven der Schale sind viel schwächer entwickelt als bei den anderen Cypridiniden.

Bei der Untersuchung des eigentlichen Körpers thun wir gut, uns über die Lage der Organe zu orientiren, ohne das Thier aus der Schale herauszulösen, und das geht einigermaassen, da die Schale ziemlich durchsichtig ist. Wir vermögen sehr wohl Herz (*C.*), Frontalorgan (*Fr.*), Schliessmuskel (*Ml.*), Darm (*D.*), Furcalfeld (*Ff.*), 2. Antenne (*An.* 2), Putzfuss (*Pf.*), sowie den Rücken des Thieres mit seinen Muskeln zu erkennen (Tafel 1, Fig. 1, 2). Die nicht genannten Gliedmaassen liegen als unentwirrbare Masse auf den kleinen Raum zwischen 2 Antenne und vorderer Grenze des Furcalfeldes zusammengedrängt. Wie aus der Figur 1 ersichtlich, überwiegt die Rückenpartie des Körpers sehr stark, diese grössere hintere Hälfte wird nur zum kleinsten Theil erfüllt von dem Magen und den Geschlechtsorganen, der Rest stellt einen ausserordentlich umfangreichen Blutraum dar. Bei dem gezeichneten Thier, wie bei allen untersuchten der Art, war der Magen leer und stark contrahirt (vergl. unten), bei gefülltem Magen wird sich das Verhältniss etwas zu Ungunsten des Blutraumes verschieben, immerhin zeigt sich das, was schon bei Besprechung der Schale erwähnt wurde, doch noch viel auffälliger als dort: Die Bluträume haben einen ausserordentlichen Umfang erlangt, ihnen gegenüber tritt die feste Substanz des Körpers sehr zurück. Es ist mir aus der Gruppe der Krebse kein Beispiel für ein ähnliches Ueberwiegen der Bluträume bekannt geworden. Versuchen wir das Thier aus der Schale auszulösen, so erfolgt beim Anschneiden der Schale ein starker Ausfluss der Körperflüssigkeit, beide Schalenlamellen legen sich dicht aneinander, der Körper fällt zusammen; augenscheinlich genügt beim Fangen eine geringe Verletzung des Thieres, um das Blut ausfliessen zu lassen und den Körper arg zu entstellen.

*Gliedmaassen.* — Allgemein lässt sich von der Mehrzahl der Gliedmaassen sagen, dass sie verhältnissmässig kürzer sind als bei anderen Cypridiniden (vergl. Tafel 3). Die 1. *Antenne* (Tafel 3, Fig. 2) ist gestreckt und ziemlich schlank, sie ist 7 gliedrig, das 5. Glied trägt die gefiederte Sinnesborste der Cypridiniden; dieselbe ist in beiden Geschlechtern gleich stark entwickelt, die Fiederung ist nicht übrig reich. Das letzte Glied, an dem sich Reste einer Verschmelzung aus 7 und 8 nicht nachweisen lassen, trägt drei lange, spärlich gefiederte, starke Tastborsten, die beim ♀ etwa $\frac{4}{3}$, beim ♂ über 2 mal so lang als die Glieder 2–7, 2 kürzere Sinnesborsten, 1 kürzere starke und eine sehr kurze schwache Borste. Beim ♂ (Tafel 1, Fig. 24) tragen einzelne Borsten ähnliche Zweige mit saugnapfartigen Gebilden wie bei *Cypridina mediterranea ;* jeder Zweig trägt nur einen kleinen Napf nahe der Basis, ist übrigens einfach. Solcher Zweige trägt die eine starke Tastborste 2, die kürzere 5. Die 2. *Antenne* (Tafel 3, Fig. 1) erinnert im Bau, wie die 1., lebhaft an die Gattung *Cypridina*, die Borste des 2. Gliedes des Schwimm oder Aussenastes ist kurz, ungefiedert, unbedornt, die übrigen Borsten sind sehr lang, gefiedert, nicht bedornt ; der Dorn, der bei *Cypridina* neben der Basis der Borsten entspringt, fehlt. Der Innenast ist beim ♀ gestreckt, deutlich dreigliedrig, trägt am Ende eine lange Borste (Taf. 1, Fig. 21), beim ♂ ist er als Greiforgan entwickelt, das 3. Glied gegen das 2. einschlagbar (Taf. 1, Fig. 18, 19).

Die *Mandibel* (Tafel 3, Fig. 6) ähnlich wie bei *Cypridina*, besonders die Kauplatte (Taf. 1, Fig. 20) von ähnlicher Gestalt, die Borsten am Vorderrand des 3. Tastergliedes stark vermehrt, die Drüse erstreckt sich distal bis in die Basis des 3., proximal nur bis in die Mitte des 1. Tastergliedes. Bemerkenswerth ist ein dichter Besatz mit feinen Haarborsten, welche in Gruppen von 3–8 beisammen stehen ; solche Gruppen finden sich am 1. Tasterglied, derber am Kaufortsatz (Tafel 1, Fig. 17, 20). 1. *Maxille* (Tafel 3, Fig. 3) von ähnlichem Bau wie bei *Cypridina*, ebenso die 2. *Maxille* (1. thoracale Gliedmaasse, Tafel 3, Fig. 4 ; Tafel 2, Fig. 8, 9). Die Borsten des letzten Gliedes sind stark vermehrt, die zahnartigen Gebilde der einen Reihe sind viel kräftiger als die der anderen, die der kräftigeren Reihe sind stark gekrümmt. Die 2. *thoracale Gliedmaasse* (Taf. 3, Fig. 7) ähnlich wie bei *Cypridina*, doch auffallend klein, mit ähnlichen Gruppen von Haarborsten wie der Mandibulartaster. *Putzfuss* (Tafel 3, Fig. 5) ausserordentlich lang und wohl entwickelt, die Ringe sehr kurz, das letzte $\frac{1}{7}$ mit sehr zahlreichen Borsten (ich schätze jederseits über 200), welche sämmtlich von typischen Bau ; das Ende mit 1 langen Reihe sehr zahlreicher kleiner Zähne, welcher Reihe nur ein einzelner kleiner Zahn gegenüber steht (Tafel 1, Fig. 15). *Furca* mit 11 Dornenpaaren (die Zahl ist anscheinend constant). Die Dornen nehmen ziemlich regelmässig von der Spitze nach der Basis zu an Grösse ab ; das in Figur 15, Tafel 2 gezeichnete Zurückbleiben des 5. Dornes findet sich nicht constant.

Die *Oberlippe* (Tafel 1, Fig. 3, *Ol.*) besteht aus einem unpaaren, nach vorn gerichteten Kamm und einem breiten, queren Wulst, welcher direct vor dem Munde liegt; die Mündungen der Drüsen finden sich am vorderen Rand des Kammes, sowie an den Seiten des queren Wulstes. Bemerkenswerth ist der Bau des *Magens* (Tafel 1, Fig. 10). Derselbe besteht aus einer inneren Epithelschicht; die Epithelzellen waren stets sehr dünn und hoch, was unzweifelhaft eine Folge der starken Contraction war, dann folgt ein structurlose, stark gefaltete Membran, dieselbe stammt vermuthlich von den Epithelzellen. Nach aussen von ihr liegen zahlreiche Muskelfasern (*Ml.*), die sich annähernd unter rechtem Winkel kreuzen, ein dichtes Netzwerk bilden, es folgt eine Schicht von Zellen, die dicht mit braunschwarzem Pigment erfüllt sind (Leberzellen), schliesslich ein dichtes Netzwerk von Bindegewebszellen, deren Ausläufer bis zum Rücken, in der Herzgegend bis zur Schale reichen; sie lassen den Magen wie mit einem dichten Pelz bekleidet erscheinen. Stets fand ich den Magen stark contrahirt und leer, augenscheinlich erfolgt im Netz oder bei der Conservirung stets eine starke Contraction und Entleerung. Bei der anderen Art, wo der Magenwand die Muskelfasern fehlen, fand ich im Magen Reste einer Salpe.

*Sinnesorgane.* — Paarige Augen. Dieselben erheben sich als kleine Warzen ziemlich frei über der Basis der 1. Antenne, hinter den Seitentheilen des Frontalorgans (Tafel 1, Fig. 3, *Oc.*). In jedem Auge finden sich 4 längliche, etwa birnförmige Blasen (die Zahl 4 scheint constant zu sein). Die Oberfläche der Blase ist glatt, auf der inneren Fläche der Wandung finden sich zahlreiche Rippen oder Leisten von stärkerem Lichtbrechungsvermögen, dieselben bilden ein Gewirr von ziemlich scharf begrenzten Linien, die einen unregelmässigen, meist geschlängelten Verlauf haben (Tafel 1, Fig. 14). Bei jüngeren Thieren ist die Anordnung der Rippen einfacher, auch zeigen sie bestimmte Beziehungen zu den zahlreichen Kernen, die sie meist im Bogen umziehen (Tafel 1, Fig. 11, da die Fig. 11 von *Gigantocypris pellucida* stammt, so ist es auch möglich, dass es sich um Artunterschiede handelt). Am proximalen, spitzen Ende geht die Blase in einen feinfasrigen Fortsatz über, den Nerven. Ich betrachte diese Blasen als eigenthümlich umgestaltete Rhabdome. Welche Function freilich diese Blasen haben, das ist schwer einzusehen. Ihre Verbindung mit einem Nerven spricht für ein Sinnesorgan, und hier scheint jede andere Deutung als die eines Sehorganes ausgeschlossen, ich komme auf die Frage noch einmal kurz zurück. Linsen habe ich in dem Auge vollständig vermisst, auch Pigment fehlte, doch kann es in Folge der Conservirung verloren gegangen sein; bei *G. pellucida* hatte die Blase ein bräunliche Färbung.

Das *Frontalorgan* ragt als grosser, nasenförmiger Körper oberhalb des

Ursprungs der 1 Antenne vor, im Profil zum Theil verdeckt durch den Stamm der 2 Antenne. Wir unterscheiden an demselben 3 in der Nase selbst liegende und 2 nahe der Nasenwurzel liegende Körper von dunklerer Färbung. Die Lage dieser Körper wird durch Fig. 3, 5, Tafel 1 veranschaulicht. Die in der Nase selbst liegende Gruppe besteht aus zwei grösseren dünnen, etwa senkrechten, nach unten divergirenden Platten (a) von annähernd dreieckiger Gestalt und einer kleineren, dünneren, länglichen Platte (b), welche sich zwischen die horizontalen Ränder der verticalen Platten schiebt. Die Platten bestehen aus einer annähernd homogenen Grundsubstanz, in der sich zahlreiche verzweigte Streifen einer dichteren, stärker färbbaren Substanz finden (Tafel 1, Fig. 12). Die Streifen sind nicht scharf gegen die Grundsubstanz abgegrenzt. Die Anordnung der Streifen lässt stellenweis ähnliche Beziehungen zu den Kernen erkennen wie beim Rhabdom (Tafel 1, Fig. 11).

Bei der horizontalen kleinen Platte, von der die Figur 12 stammt, ist das Bild ein ziemlich übersichtliches, in Folge der geringen Dicke der Platte liegen alle Streifen annähernd in einer Ebene, complicirter wird das Bild an den dickeren, verticalen Platten, bei denen die Zahl der dichteren Streifen eine grössere; bei den seitlichen Körpern (Fig. 3, 5 c), die einen etwa ovalen Querschnitt besitzen, ist sie naturgemäss am grössten; die Oberfläche derselben bietet das Bild einer sehr dichten, welligen Querstreifung (Tafel 1, Fig. 13). Auf Schnitten (Tafel 1, Fig. 4) zeigt sie sich in ganzem Umfang durchsetzt von dichteren, mit einander anastomosirenden Streifen. Die Innervirung erfolgt bei den seitlichen Körpern von der distalen Fläche aus, bei den senkrechten Lamellen anscheinend von der äusseren, bei der kleinen verticalen von der unteren Fläche, doch habe ich bei den zuletztgenannten keine volle Klarheit erlangt.* Die Kerne liegen stets lediglich an derjenigen Fläche, oder nahe derjenigen Fläche, an welcher die Nerven an den Körper herantreten. Die beiden seitlichen Körper sind von einem bräunlichen Pigment umhüllt, das einer sehr dünnen, structurlosen Membran aufliegt. Die Grenzen der Pigmentirung habe ich nicht sicher feststellen können. Der mittleren Gruppe scheint eine pigmentirte Hülle zu fehlen, doch dürfte es sich auch hier um einen Verlust des Pigmentes in Folge der Conservirung handeln.

Was die morphologische Deutung des Organs anbetrifft, so habe ich schon ausgesprochen, dass ich es als das Frontalorgan anspreche, und zwar halte ich die mittlere Gruppe für homolog dem unteren Abschnitt anderer Cypridiniden, die seitlichen Körper den oberen paarigen Abschnitten. An Stelle der Gruppen von Sehstäbchen sind solide Körper von ähnlicher Zusammensetzung getreten. Bei den seitlichen Körpern (c) erkennt man ohne Weiteres die Übereinstimmung in der Art der Innervirung und Lage der Kerne. Wie bei den übrigen Cypridiniden haben wir dichtere und stärker lichtbrechende Stäbchen, welche einer homogenen Masse eingebettet sind, an der man häufig Zellgrenzen nicht zu erkennen vermag. Der wesentliche Unterschied würde in der Beschaffenheit der Stäbchen liegen, die hier viel länger und wellig gebogen sind, sich verzweigen, mit einander anastomosiren. Weniger klar liegen die Verhältnisse bei der mittleren Gruppe. Wir müssen annehmen, dass der ursprünglich einfache Abschnitt zunächst in drei kleinere Körper zerfallen ist. Bei der flächenhaften Entwicklung dieser Körper mussten die Sehstäbchen ihre Lage ändern, sie entwickelten sich parallel der Oberfläche der Körper. Der zitzen oder stabförmige Fortsatz des Frontalorgans fehlt; nur eine seinem Basalstück entsprechende Anhäufung von Kernen am unteren Rand der Nase und an der Nasenspitze ist als Rest desselben aufzufassen.

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* Ich muss die Unbestimmtheit der Resultate mit dem geringen Material, auf das ich angewiesen war, entschuldigen. Nur das eine wohl erhaltene ♂ lieferte für die Untersuchung des Frontalorgans brauchbare Resultate.

Das *Herz* ist auffallend zart und dünnhäutig, so dass es bei der Präparation des Thieres vollständig zusammenfällt. Der ausserordentlichen Vermehrung der Leibeshöhlenflüssigkeit entspricht also nicht eine Verstärkung des Circulationsapparates, im Gegentheil; ich vermuthe dass das Herz kaum noch functionirt. Die männlichen *Geschlechtsorgane* schliessen sich im Bau eng denen anderer Cypridiniden an, die weiblichen Geschlechtsorgane konnte ich nicht genauer untersuchen, da sämmtliche ♀ stark verdrückt waren; die Eier werden in grosser Zahl im Brutraum getragen. Der *Schliessmuskel* ist sehr schwach im Verhältniss zur Grösse des Thieres, die Zahl der Muskelbündel ist gering, die Bündel selbst sind schwach, doch zeigen sie deutliche Querstreifung.

Versuchen wir aus der Organisation des Thieres uns eine Vorstellung seiner Lebensweise zu bilden! Schon Eingangs sprach ich die Vermuthung aus, dass die Art ausschliesslich frei schwimmend lebt, sich nicht am Grunde bewegt. Für die Mehrzahl der Cypridiniden lehrt die Beobachtung des lebenden Thieres, dass dieselben vorwiegend an den Grund gebunden sind, aber auch für die Halocypriden, die man gewöhnlich als rein pelagische Formen betrachtet, habe ich die Ansicht ausgesprochen, dass sie sich wenigstens zeitweis am Grund aufhalten. Die Gründe, die ich für diese Ansicht an anderem Ort (Monographie der Ostracoden, p. 13) geltend machte, waren im wesentlichen folgende: 1. das hohe specifische Gewicht, besonders bedingt durch die Verkalkung der Schale; 2. die Körperform, der Mangel flächenhafter Ausbreitung, die ein freies Schweben ganz ohne oder mit nur geringem Kraftaufwand nicht gestattet; 3. der Bau der Gliedmaassen, welche zum Theil zum Anklammern geeignet sind. Wie verhält sich in dieser Beziehung *Gigantocypris?* Wie gesagt, fehlt der Schale jede Spur von Kalkablagerung, zudem tritt die feste Substanz der Leibeshöhlenflüssigkeit gegenüber sehr zurück, das specifische Gewicht kann kaum höher als das des umgebenden Mediums sein. Flächenhafte Ausbreitungen fehlen so gut wie bei anderen Ostracoden, doch ist, wie gesagt, der Umfang im Verhältniss zur Körpermasse ein sehr grosser, so dass man sich sehr wohl denken kann, dass das Thier ohne Zuhülfenahme seiner Ruder wie eine leichte Blase durch das Wasser treibt, ohne unterzusinken.

Von besonderem Interesse ist eine Betrachtung der Gliedmaasen. Die Gliedmaassen aller Cypridiniden sind ungeeignet zum Kriechen und Anklammern, und das gilt auch von *Gigantocypris,* wohl aber vermögen die Mehrzahl der Cypridiniden sich in den Grund einzugraben, die Gliedmaassen zeigen mancherlei Anpassung an diese Lebensweise, welche Anpassungen allerdings gerade bei der *Gigantocypris* am nächsten verwandten Gattung *Cypridina* am wenigstens ausgebildet sind. Wie verhält sich in dieser Beziehung *Gigantocypris?* Die 1. Antenne betheiligt sich bei *Cypridina* am Eingraben, bei *G.* ist sie viel schlanker, zum Eingraben weniger geeignet, besondere als Anpassungen an das Eingraben aufzufassende Eigenthümlichkeiten fehlen beiden Gattungen. 2. Antenne: Die Borste des 2. Schwimmastgliedes ist bei *Cypridina* kurz, ungefiedert, bedornt, bei *Gigantocypris* ebenfalls kurz, ungefiedert, aber unbedornt. Der Dorn, der bei *Cypridina* neben jeder Schwimmborste entspringt, und vermuthlich ebenfalls dem Eingraben dient, fehlt. Der Mandibulartaster betheiligt sich ebenfalls am Eingraben, er ist bei *Gigantocypris,* vergleichen mit der Maxille, verhältnissmässig kürzer als bei *Cypridina,* übrigens wohl entwickelt, was sich aus seinem Antheil an der Nahrungsaufnahme erklärt. Eine hervorragende Rolle spielt die Furca beim Eingraben, sie ist bei *Gigantocypris* auffallend kurz und schwach entwickelt, besonders sind die Dornen dünn und zerbrechlich. Wird die Furca nicht mehr zum Eingraben verwendet, so erscheint eine Gliedmasse, bestimmt die Furca abzubürsten ziemlich überflüssig, und in der That ist die 2. thoracale Gliedmaasse (Tafel 3, Fig. 7) ziemlich schwach entwickelt, während der Putzfuss eine ausserordentliche Länge erreicht, entsprechend der grossen Fläche, die er zu reinigen hat.

Uebrigens bedarf es kaum dieser Thatsachen, um den Beweis zu liefern, dass sich *Gigantocypris* nicht einzugraben vermag; der Umfang und die Zartheit der Schale allein würden eine ähnliche Bewegung unmöglich machen. Ich glaube nach allem Gesagten, dass sich *Gigantocypris* ausschliesslich frei schwimmend bewegt, nach meiner Auffassung würde es der einzige bis jezt bekannt gewordene Ostracode mit dieser Lebensweise sein.

Mit der Frage nach der Art der Bewegung berührt sich eng eine andere, die, nach der Möglichkeit, die Schale zu öffnen. Nach der Darstellung, die ich oben vom Bau der Schale gegeben habe, drängt sich die Vorstellung auf, dass das Thier die Schale gar nicht zu öffnen vermag, das würde schon daraus folgen, dass beide Schalenhälften für $\frac{2}{3}$ ihrer Peripherie fest mit einander verbunden sind. Auch die geringe Entwicklung des Schliessmuskels scheint diese Annahme zu befürworten. Man könnte sich wohl vorstellen, dass nur die 1. und 2. Antenne durch die Rostralincisur herausgestreckt werden könnten, dass sich, abgesehen vom Umherschwimmen, die Thätigkeit des Thieres darauf beschränkte, durch die Bewegung der 1. thoracalen Gliedmaasse (2. Maxille) einen Wasserstrom zu erzeugen, der bei geschlossener Schale durch die Rostralincisur ein, durch die hintere Oeffnung austräte und sowohl die Athmung vermitteln als auch die Nahrung zuführen würde. Im allgemeinen mag sich in der That das Leben der Thiere in dieser Weise abspielen, doch sprechen einige Gründe dafür, dass doch ein gewisses Oeffnen der Schale erfolgen kann; so wäre es unmöglich, die Beute, die ich ziemlich unzerkleinert im Magen von *G. pellucida* fand, durch die Rostralincisur allein in den Schalenraum und zum Mund zu bringen; weiter wäre eine Begattung, ein Vorstrecken des Penis ohne Oeffnen der Schale unmöglich. Unzweifelhaft ist aber der Mechanismus beim Oeffnen der Schale ein wesentlich anderer, es können nicht beide Schalenhälften als Ganzes von einander entfernt, sondern es können nur die Ränder auseinandergebogen werden, während die übrige Schale nur zum kleineren Theil in Mitleidenschaft gezogen wird; das würde ja auch bei der Weichheit und Biegsamkeit der Schale sehr wohl möglich sein. Immerhin scheint ein solches Oeffnen den postoralen Gliedmaassen und der Furca nur wenig Spielraum zur Bewegung zu lassen.

Noch bleibt die Frage zu erörtern, in welcher Beziehung die sehr auffällige Umgestaltung der Sehorgane zur Lebensweise steht? Da die gesammelten Thiere z. Th. aus bedeutender Tiefe stammen, so liegt der Gedanke nah, dass wir in der eigenthümlichen Form eine Anpassung an das Leben in grosser Tiefe zu sehen haben; vielleicht sind diese merkwürdigen Augen befähigt, noch bei sehr schwachem Licht Differenzen in der Helligkeit wahrzunehmen. Ich lasse noch eine kurze Gattungsdiagnose, sowie eine Differentialdiagnose beider Arten folgen.

### **Gigantocypris**, nov. gen.

Schale dünn und zart, nicht verkalkt, beide Schalenhälften nur undeutlich gegen einander abgegrenzt, für etwa $\frac{2}{3}$ der Peripherie mit einander verschmolzen, mit kleiner, aber deutlicher Rostralincisur. Körper stark aufgetrieben. 1. Antenne gestreckt, 7 gliedrig, Sinnesborste des 5. Gliedes schwach gefiedert, in beiden Geschlechtern gleich; beim ♂ 2 Borsten des letzten Gliedes mit Haftorganen; 2 Antenne: die erste Borste des Schwimmastes kurz, ungefiedert, unbedornt. Innenast dreigliedrig, beim ♂ als Greiforgan functionirend, das letzte Glied einschlagbar, Mandibel mit einfachem, einspitzigem, rückwärts gerichtetem Fortsatz des Basalgliedes und wohl entwickeltem 4 gliedrigem Taster, 1. Maxille von typischem Bau, mit 3 Kaufortsätzen und 3 gliedrigem Taster. 1. thoracale Gliedmaasse (2. Maxille) mit 2 Reihen zahnartiger Borsten. 2. thoracale Gliedmaasse deutlich 4 gliedrig, mit schwacher Musculatur. Putzfuss sehr lang, mit sehr zahlreichen Borsten und einer Reihe kleiner Zähne. Furca ohne deutliche Differenzirung in Haupt und Nebendornen. Oberlippe umfangreich, ohne zitzenartige Fortsätze, die Mehrzahl der Drüsen mündet auf einer Kante am Vorderrand. Frontalorgan sehr umfangreich, die oberen Gruppen weit von der mittleren getrennt, die mittlere in 3 Körper aufgelöst, ohne zitzen oder stabförmigen Fortsatz. Paarige Augen vorhanden (in beiden Geschlechtern ?), mit 4 eigenthümlich umgestalteten, blasenförmigen Elementen, ohne Linsen.

Wie schon hervorgehoben, schliesst sich *Gigantocypris* der Gattung *Cypridina* eng an, zeigt eine weitgehende Uebereinstimmung im Bau der Gliedmaassen. Als unterscheidende Merkmale wären hervorzuheben: der Bau der Schale, der Oberlippe und des Frontalorganes. Die oben gegebene Beschreibung bezog sich auf *Gigantocypris Agassizii*, neben dieser durch 5 Individuen (4 ♀, 1 ♂) vertretenen Art fand sich noch ein Individuum einer zweiten Art; obwohl nur ein noch nicht geschlechtsreifes ♂ vorlag, habe ich doch geglaubt, bei dem besonderen Interesse, welches sich an die Gattung knüpft, die Art beschreiben zu sollen, zumal scharfe unterscheidende Merkmale existiren.

### **Gigantocypris pellucida**, n. sp.

Schale, Gliedmaassen und sonstiger Körperbau wie bei *Agassizii*; am Putzfuss war die Zahl der Zähne in der Reihe an der Spitze viel kleiner

(7 anstatt etwa 60; Tafel 1, Fig. 16, 15). Neben den typischen Borsten (Tafel 1, Fig. 23), existiren solche mit einfachem pinselartigem Ende (Fig. 22), letztere sind viel seltner als die erstgenannten. In der Magenwand fehlen die Muskelfasern, an ihrer Stelle finden sich nur dünne, anscheinend nicht contractile Fasern, entsprechend ist der Darm an conservirtem Material nicht contrahirt; ferner fehlen die zur Leibeswand verlaufenden Bindegewebsfasern. Das untersuchte Thier stand vor der zur Geschlechtsreife führenden Häutung, es mass 16 mm., danach dürfte die Art etwas kleiner sein als *Agassizii.*

Vorkommen: Sämmtliche Thiere sind gefischt nahe der Westküste von Central Amerika, nämlich:—

| | |
|---|---|
| 0° 36′ n. Br. | 82° 45′ w. L. |
| 0° 54′ n. Br. | 91° 9′ w. L. |
| 2° 34′ n. Br. | 92° 6′ w. L. |
| 26° 48′ n. Br. | 110° 45′ w. L. |
| 27° 3′ n. Br. | 111° 0′ w. L. |

in Tiefen von etwa 1700 Faden bis 100 Faden (offenes Netz).

Vermuthlich bezieht sich auch die folgende Angabe* auf eine Art der Gattung *Gigantocypris:* Der Challenger brachte zwischen den Prinz Edwards und Crozet Inseln aus einer Tiefe von 1375 oder 1600 Faden mit dem Schleppnetz einen Ostracoden herauf, dessen weiche, skulptirte Schale eine Länge von 25 mm. und eine Höhe von 16 mm. hatte. Der Deckel (?) allein ist 3 mm. lang. Wahrscheinlich gehört dieser Ostracode, von dessen Körper nur der Kopf erhalten ist, zu keiner der bis jezt bekannten Familien. Die Angabe, dass nur der Kopf erhalten sei, dürfte sich vielleicht aus der geringen Grösse des Körpers, vergleichen mit der Schale, erklären. Leider fehlen nähere Angaben über das Thier, in den Challengerostracoden ist es nicht erwähnt.

## HALOCYPRIDÆ.

Gesammelt sind 4 Arten *Conchœcia* (*Conchœcissa*) *armata* Cls., 1 ♀ gefangen unter 10° 14′ n. Br. 96° 28′ w. L. in 100 Faden Tiefe. Ferner je 1 ♀ von 2 unbeschriebenen Arten; da der Fund zu einer scharfen Characterisirung der Arten nicht genügt, unterlasse ich es, die Arten zu beschreiben. Schliesslich fand sich ein reichliches Material einer sehr stattlichen *Conchœcia:*

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* Briefe von der Challengerexpedition von R. v. Willemoes—Suhm. Zeitschrift wissensch. Zoologie, Bd. 24, p. XIII.

### Conchœcia Agassizii, n. sp.

**(Tafel 2, Fig. 1–7, 12–14, 16–18.)**

Schale sehr derb, ungewöhnlich derb und widerstandsfähig für einen Halocypriden, besonders für eine *Conchœcia*, indessen im Verhältniss zum Körper zu klein, so dass sie den Körper nicht ganz umhüllt, vielmehr stark klafft. Die des ♀ nicht ganz noch einmal so lang wie hoch (Höhe zur Länge etwa 1 : 1,9), am breitesten etwa auf $\frac{2}{3}$ der Länge, von wo sich die Schale stark nach vorn verschmälert, hintere untere Ecke breit gerundet, der Hinterrand gerade, bildet mit dem Dorsalrand einen spitzen Winkel mit abgerundeter Spitze. Rechte und linke obere Ecke nicht deutlich verschieden. Schale des ♂ etwas gestreckter, etwas über noch ein mal so lang wie hoch, nach vorn weniger stark verschmälert; der Winkel, welchen Dorsal- und Hinterrand mit einander bilden, grösser als beim ♀, doch immer noch kleiner als ein rechter, der Rostralfortsatz des ♂ nur wenig stärker in die Höhe gebogen als beim ♀, mit kurzer, abgesetzter Spitze. In beiden Geschlechtern zeigt die Schale eine schwach entwickelte, nur schwer nachweisbare Skulptur; dieselbe besteht aus zahlreichen undeutlichen Linien, welche in der vorderen Hälfte eine parallele Streifung oder langgestreckte Rhomben, in der hinteren Hälfte eine polygonale Felderung bilden. Die Streifen verlaufen annähernd senkrecht zur Rückenlinie. Die unsymmetrischen Drüsengruppen sind wohl entwickelt, die Männchendrüsen habe ich nicht auffinden können.

1. Antenne des ♂: die Hauptborste sehr lang, über 3 mal so lang als die 1. Antenne, mit sehr zahlreichen rückwärts gerichteten Spitzen, ich zähle gegen 100 Paare; die Paare stehen sehr dicht und regelmässig neben einander, so dass die eine Spitze die benachbarte im Profil verdeckt, folgen sich sehr dicht, verändern proximalwärts Gestalt und Anordnung nicht oder nur unbedeutend; auf die rückwärts gerichteten Spitzen folgen distal noch einige schwächere, vorwärts gebogene borstenartige Anhänge (Tafel 2, Fig. 18). Die zwei schwächeren Borsten sind annähernd gleich lang, etwas länger als die halbe Hauptborste, sie tragen einzelne vorwärtsgerichtete Spitzen. Von den beiden Sinnesborsten erreicht die distale eine Länge von mehr als $\frac{2}{3}$ der 1. Antenne, sie ist sonst in der Gattung *Conchœcia* durchweg viel kürzer. Beim ♀ ist die 1. Antenne viel schwächer als beim ♂, zeigt aber eine wohl entwickelte Muskulatur, die Hauptborste erreicht die 2–3fache Länge der 1. Antenne, die 4 gleichlangen Sinnesschläuche etwa die Länge der 2 ersten Glieder.

Nebenast der 2. Antenne des ♂ (Tafel 2, Fig. 3–5, 7): das Basalglied von typischer Form, die eine Borste dünn gefiedert, das 2. Glied trägt ausser den 2 starken endständigen Borsten gegenüber dem Ursprung des letzten Gliedes zwei schwache, schlanke Borsten, von den beiden endständigen Borsten erreicht die eine eine ausserordentliche Länge, ist etwa doppelt so lang wie der Aussenast mit seinen Schwimmborsten, die andere erreicht nicht ganz die halbe Länge der ersten. Am letzten hakenartig gebogenen Glied bleiben die 3 Borsten sehr kurz, erreichen etwa nur $\frac{1}{8}$ der längsten Borste des Innenastes, der Haken ist auf beiden Seiten stark gebogen, in eine Spitze ausgezogen, rechts und links in der Gesammtform nicht sehr verschieden; auf der einen Seite zeigt er nahe der Basis 2 einander gegenüberstehende zahnartige Vorsprünge.

Beim ♀ (Tafel 2, Fig. 6, 13) ist der Nebenast kürzer, die längste Borste erreicht noch nicht $\frac{2}{3}$ der Länge wie beim ♂, die Borsten des letzten Gliedes bleiben wie beim ♂ sehr kurz, an Stelle der 2 überzähligen Borsten des vorletzten Gliedes beim ♂ findet sich nur eine. Beide Borsten des 1. Gliedes sind ungefiedert.

Frontalorgan mit einfachem, erweitertem Endstück, dessen Form nicht besonders charakteristisch; das des ♀ dem des ♂ ähnlich, nicht ganz noch einmal so lang als die 1. Antenne, das erweiterte, nicht beweglich abgesetzte, stark bedornte Endstück schlanker als beim ♂.

Das Thier erreicht eine Grösse von 4,8 mm.

Gefischt im Golf von Californien in einer Tiefe von etwa 700 Meter (offenes Netz).

## FIGURENERKLAERUNG.

| | | | |
|---|---|---|---|
| *a. L.* | Aeussere Lamelle. | *N.* | Nerv. |
| $An_1$, $An_2$. | Erste, zweite Antenne. | *Oc.* | paariges Auge. |
| *C.* | Herz. | *Oe.* | Œsophagus. |
| *D.* | Darm. | *Ol.* | Oberlippe. |
| *Dr.* | Drüsenmündung. | *Pe.* | Penis. |
| *F.* | Furca. | *Pf.* | Putzfuss. |
| *Ff.* | Furcalfeld. | *R.* | Rand. |
| *Fr.* | Frontalorgan. | $R_1$. | innere Randleiste. |
| *G.* | Gehirn. | *S.* | Saum. |
| *i. L.* | innere Lamelle. | *T.* | Hoden. |
| *Ir.* | Innenrand. | *Vl.* | Verwachsungslinie. |
| *Ml.* | Muskel. | | |

## TAFEL 1.

Fig. 1–5. *Gigantocypris Agassizii.*
Fig. 1, 2. ♂, ganzes Thier, von der Seite und von unten. 3 ×
Fig. 3. Ventrale Körperhälfte nach Entfernung der Gliedmaasen. 7 ×. Die Buchstaben a, b, c, bezeichnen die gleichen Theile wie in Fig. 5.
Fig. 4. Schnitt durch einen seitlichen Körper (c) des Frontalorganes. 100 ×
Fig. 5. Frontalorgan von vorn. 7 × (a, b, c vergl. Fig. 3).
Fig. 6, 7. *Gigantocypris pellucida* ♂ juv. Rostralincisur und hinteres Ende des Schalenschlitzes von vorn, resp. unten. 7 ×
Fig. 8–10. *Gigantocypris Agassizii.*
Fig. 8, 9. ♂ Rostralincisur und hinteres Ende des Schlitzes von innen. 8 ×
Fig. 10. ♀ Schnitt durch die Magenwand. 162 ×
Fig. 11. *Gigantocypris pellucida.* Einzelnes Rhabdom. 100 ×
Fig. 12–15. *Gigantocypris Agassizii.*
Fig. 12. ♂ Distales Ende des Körpers b des Frontalorganes von der Fläche. 100 ×
Fig. 13. ♀ Körper c. des Frontalorganes. 30 ×
Fig. 14. ♂ Stück eines Rhabdoms. 162 ×
Fig. 15. ♀ Spitze des Putzfusses. 100 ×
Fig. 16. *Gigantocypris pellucida.* ♂ juv. Spitze des Putzfusses. 100 ×
Fig. 17–21. *Gigantocypris Agassizii.*
Fig. 17. ♀ Stück vom 1. Tasterglied der Mandibel. 66 ×
Fig. 18, 19. ♂ Spitze des Innenastes der 2. Antenne, 162 ×, und Innenast. 30 ×
Fig. 20. ♀ Kaufortsatz der Mandibel. 66 ×
Fig. 21. ♀ Innenast der 2. Antenne. 30 ×

Fig. 22, 23. *Gigantocypris pellucida.* ♂ juv. Spitzen von 2. Borsten des Putzfusses. 400 ×

Fig. 24. *Gigantocypris Agassizii.* ♂ 2 letzten Glieder der 1. Antenne mit einem Theil der Borsten (weggelassen sind die 2 Sinnesborsten und eine starke Borste des letzten Gliedes). 66 ×

## TAFEL 2.

Fig. 1–7. *Conchœcia Agassizii.*

Fig. 1, 2. Schale im Profil 1 ♂, 2 ♀; 19 ×

Fig. 3. ♂ Innenast der 2. Antenne mit der Basis der Borsten, von innen, unter Deckglas. 100 ×

Fig. 4. ♂ 2 Letzten Glieder des rechten Innenastes. 100 ×

Fig. 5. ♂ Rechter Innenast. 26 ×

Fig. 6. ♀ Innenast, frei liegend, sonst wie 3. 100 ×

Fig. 7. ♂ Rechter Innenast, frei liegend, sonst wie 3. 100 ×

Fig. 8–10. *Gigantocypris Agassizii.*

Fig. 8, 9. Kautheil der 1. thoracalen Gliedmasse (2. Maxille) von innen, 26 × und Zähne beider Zahnreihen. 100 ×

Fig. 10. Erster Furcaldorn von aussen. 50 ×

Fig. 11. *Gigantocypris pellucida.* ♂ juv. Furca und Anlage des Penis von vorn. 7 ×

Fig. 12–14. *Conchœcia Agassizii.*

Fig. 12. ♀ Kaufortsatz der Mandibel von innen, am Taster haftend. 216 ×.

Fig. 13. ♀ Innenast der 2. Antenne. 26 ×

Fig. 14. ♀ 1. Antenne und Frontalorgan. 66 ×

Fig. 15. *Gigantocypris Agassizii* ♀ Furca (nur ein Ast ist gezeichnet). 19 ×

Fig. 16–18. *Conchœcia Agassizii* ♂.

Fig. 16. 1. Antenne und Frontalorgan, rechte Antenne entfernt. 66 ×

Fig. 17, 18. Bezahntes Stück einer Nebenborste und Ende der Zahnreihe der Hauptborste der 1. Antenne, beides 400 ×

## TAFEL 3.

Sämtliche Figuren stellen Gliedmaassen eines geschlechtsreifen ♀ von *Gigantocypris Agassizii* von 23 mm. Schalenlänge dar; alle Figuren 10 × vergrössert.

Fig. 1. 2. Antenne.

Fig. 2. 1. Antenne.

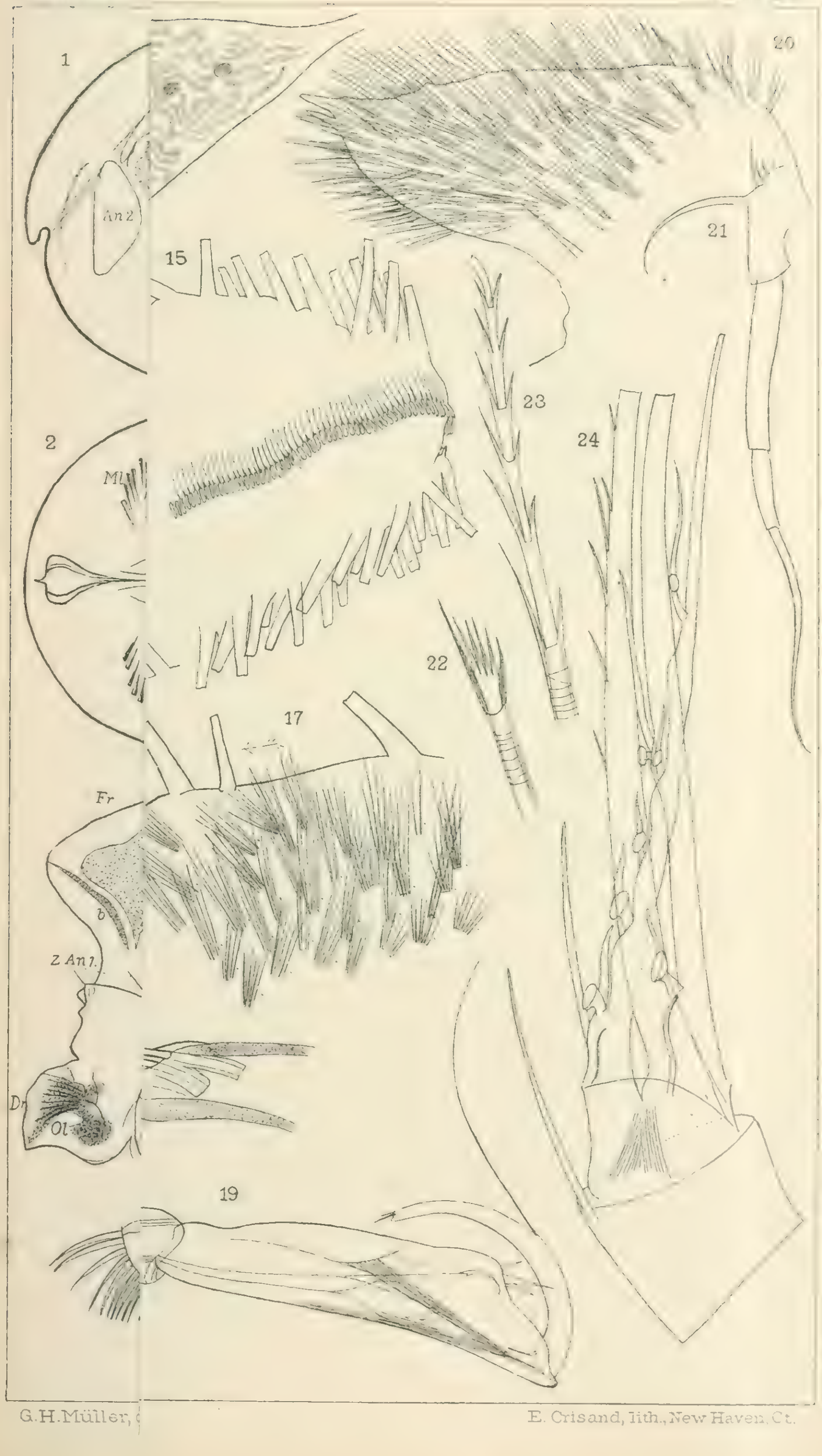
Fig. 3. 1. Maxille.

Fig. 4. 1. thoracale Gliedmaasse (2. Maxille).

Fig. 5. Putzfuss.

Fig. 6. Mandibel.

Fig. 7. 2. thoracale Gliedmaasse.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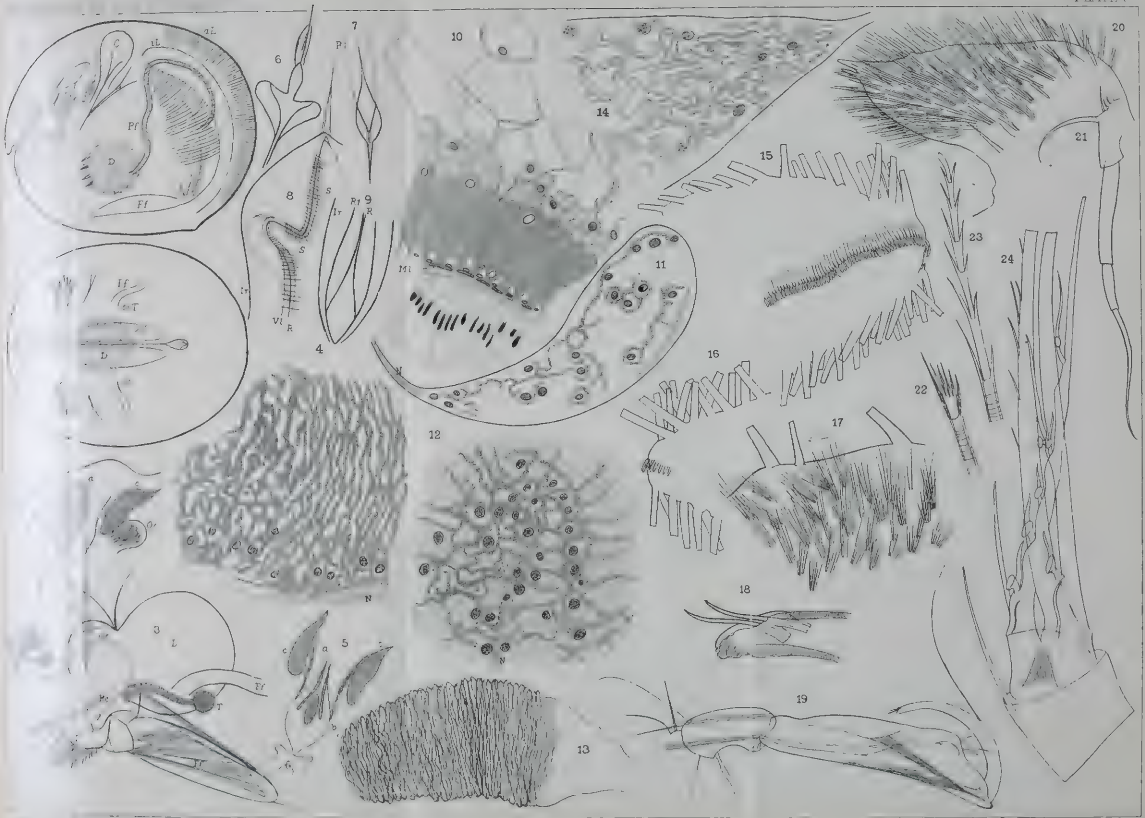
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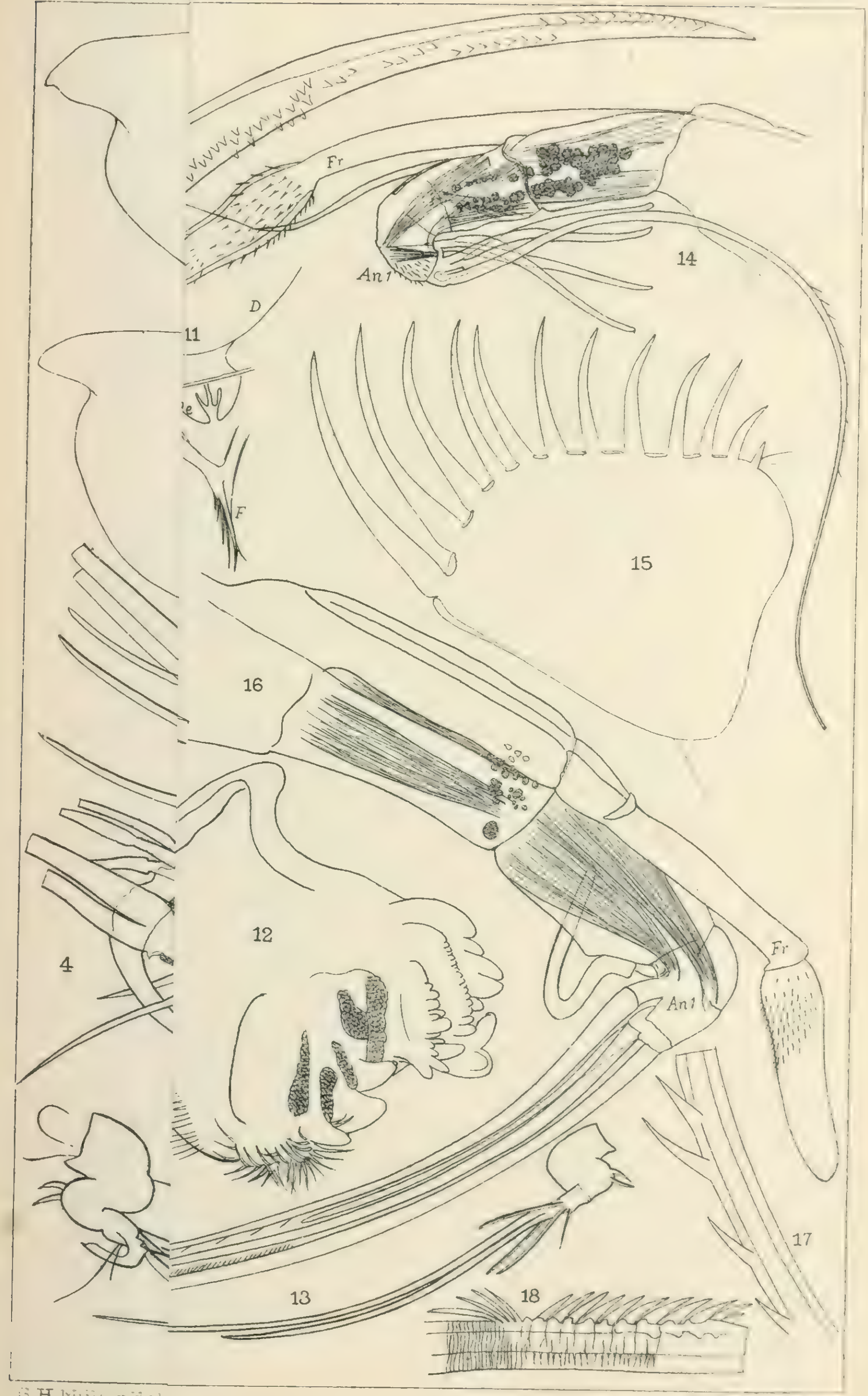
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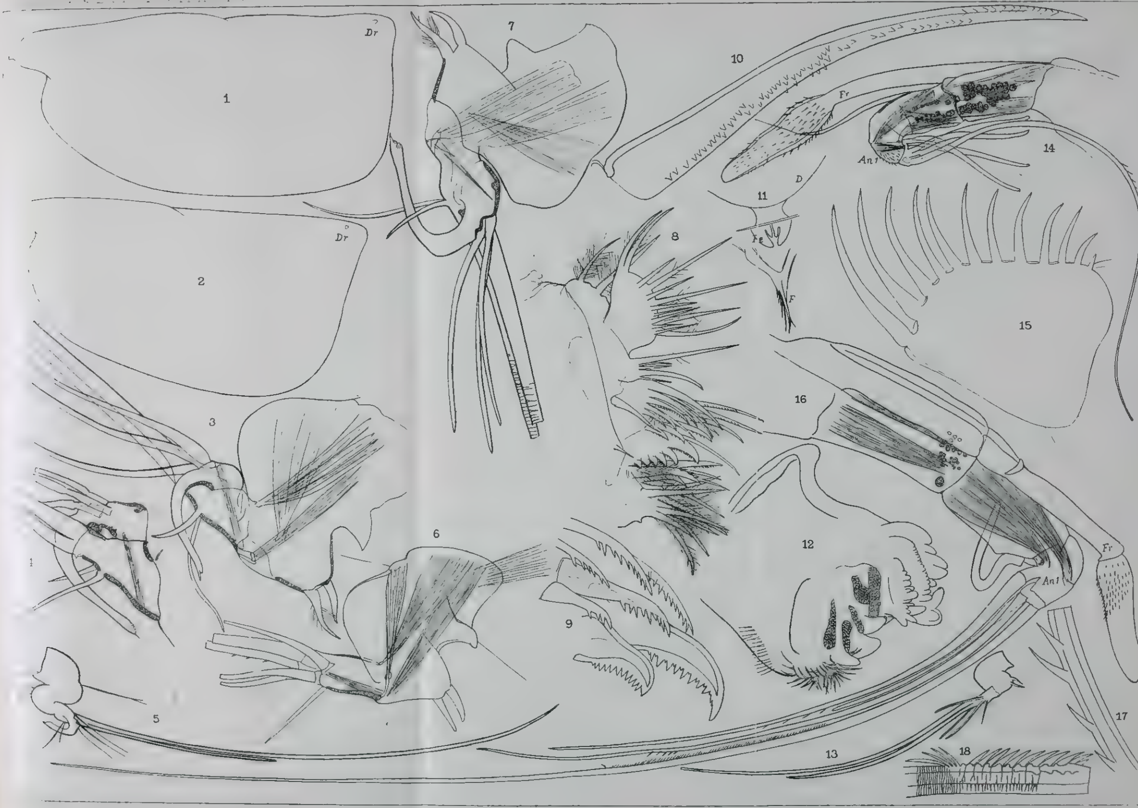
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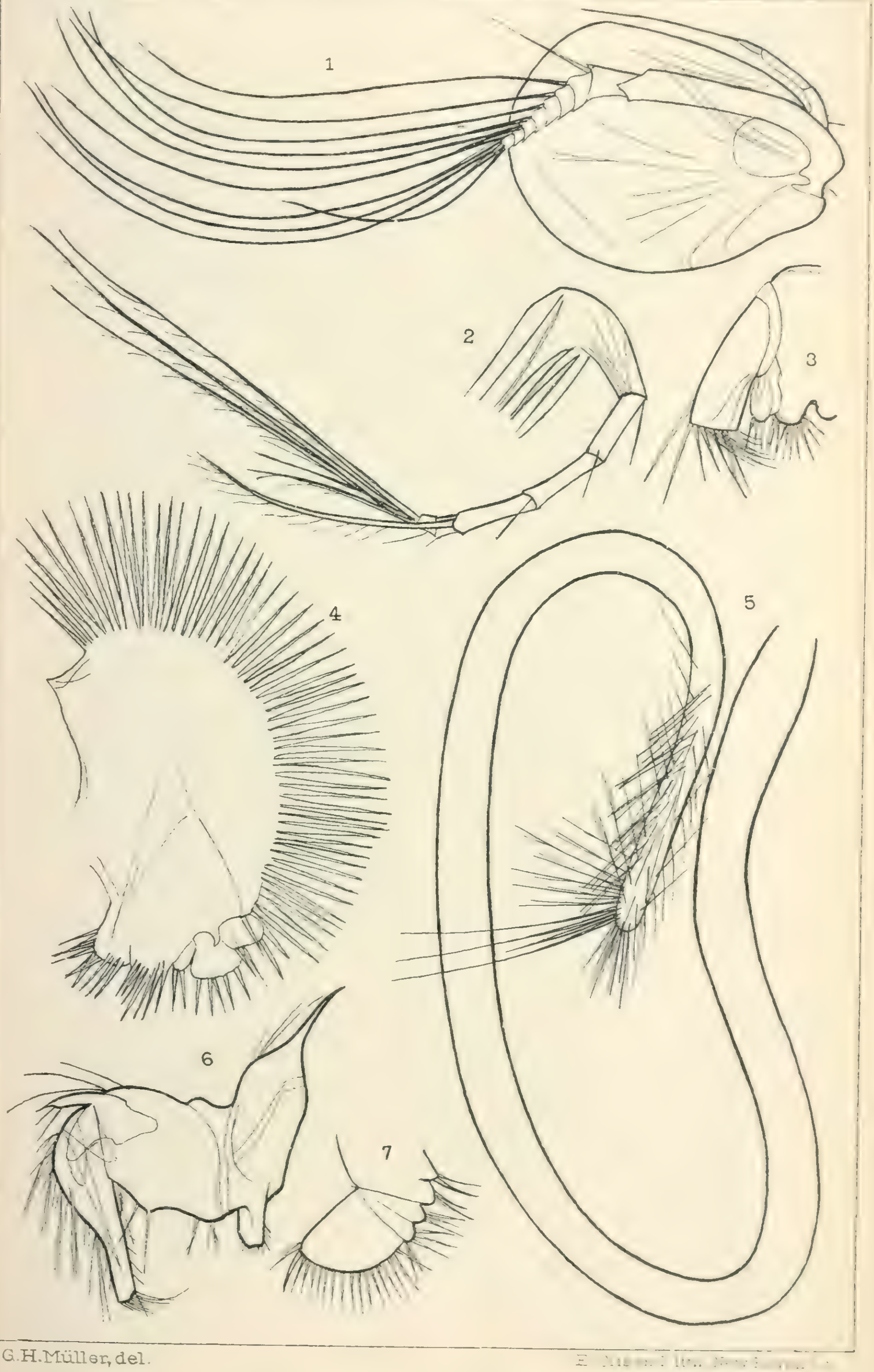

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# *No.* 6. — *Studies in Morphogenesis.* — IV. *A Preliminary Catalogue of the Processes concerned in Ontogeny.*[1] By C. B. Davenport.

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Most important perhaps of all the problems which the biologist sees lying unsolved before him is that of the development of the individual, — a problem to which, from the time of Aristotle, zoölogists have repeatedly turned, although scarcely hoping for its eventual solution.

Without attempting to consider the various theories of Ontomorphogenesis which have at different times been offered, it is sufficient to state that it is now generally agreed that ontogenesis is a process, or rather a complex of processes, taking place in the protoplasm of the developing individual.

Now it is a highly probable belief that no movement takes place in protoplasm except as a response to stimuli. The very fact that ontogenesis is a complex of actions indicates that there must be a large number of stimuli raining in upon the different parts of the developing protoplasm to which they respond.

In order to gain some idea of what the stimuli are, it is first necessary to analyze the ontogenetic complex of processes into its simple elementary ones.

It is the aim of this paper to make such an analysis into the elementary ontogenetic processes as a basis for determining the nature of the exciting stimuli.

---

[1] Contributions from the Zoölogical Laboratory of the Museum of Comparative Zoölogy at Harvard College, E. L. Mark, Director, No. L.

Other authors have devoted chapters to "Developmental Processes," but none of these can be considered as at all complete.

Thus O. Hertwig, in his "Text-Book of the Embryology of Man and Mammals" (English Translation by E. L. Mark, 1892, p. 76), has a "General Discussion of the Principles of Development." He recognized two main ones: (1) the principle of unequal growth (producing folds which are either invaginations or evaginations, and which may unite along their edges); and (2) the principle of histological differentiation.

Minot, in his Human Embryology, in a chapter on "Differentiation," seems to think also that these two processes are sufficient to explain the differentiation of organs.

More important in this connection than either of the preceding is the recent paper of Herbst in the "Biologisches Centralblatt" (Vol. XIV. Nos. 18–22). This author, after reviewing the literature upom taxism and tropism, explains as phenomena of the same order certain ontogenetic processes. He has not, however, attempted to catalogue all the ontogenetic processes.

Before beginning the present catalogue, I may state that I distinguish between ontogenetic *principles* and ontogenetic *processes*. Under the first head I include such laws of development as terminal growth, repetition of parts and bilateral symmetry in development. These I have not attempted to catalogue. The present paper is concerned only with the latter group, which comprises the different elementary operations or actions exhibited in ontogeny.

These may be divided into two classes: 1. the grosser ontogenetic pro cesses; and 2. histogenic processes. This paper deals with the first class only.

In discussing the grosser ontogenetic processes we may distinguish (A) those of a more general nature from (B) the more special ones.

A. The *general ontogenetic processes* comprise those of a general physiological character. Of these, at least three are commonly recognized: —

1. Growth (including both the results of assimilation and of imbibition of water).
2. Nuclear division.
3. Secretion.

B. The *special* ontogenetic processes are differential in character, i. e. the differentiation of the body is effected by them.

These processes may be classified, first of all, according to the form of the protoplasmic bodies in which they occur. These exist either as (I.) isolated cells, or as larger multinucleated bodies. Of the latter we may recognize three classes: (II.) bodies extended chiefly in one direction, — threads, fibres, tubules; (III.) those which extend as a layer; and (IV.) those in which the three dimensions are more nearly equal, forming solid masses.

I propose now to discuss the processes occurring in each of these four classes.[1]

## I. ONTOGENETIC PROCESSES OCCURRING IN MIGRATORY PROTOPLASMIC BODIES — MESENCHYME.[2]

1. *Migration of Nodal Thickenings in a Protoplasmic Mesh-work.* This process is found, for example, in many Arthropod eggs before the formation of the peripheral blastoderm. (Figure 1.) No one can doubt that protoplasm extends throughout the whole egg in the form of a mesh- or foam-work, whose interspaces are filled with yolk. The protoplasm is aggregated around the nuclei at certain nodal points, which later migrate to the surface or through the yolk as vitellophags. Cf. K. & H.,[3] Figs. 7, 363, 417, 448, 472, 473, 771.

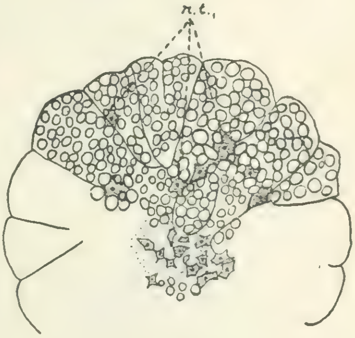

FIG. 1.

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[1] It may be a cause of dissatisfaction to some that this classification is not "strictly dichotomous"; it is still more serious that the different heads are not of co-ordinate rank or mutually exclusive. Of course, the classification employed in this list cannot be regarded as a final one. I hope, however, that I have succeeded in an attempt roughly to arrange the different items in a logical fashion.

[2] In the present paper the word "mesenchyme" is used as a name for all amœboid, migrating cells, of whatever origin.

[3] Throughout this paper certain abbreviations are used in referring to the books from which the figures are copied. These are: K. & H. for Korschelt und Heider's "Entwicklungsgeschichte"; M. for Minot's "Human Embryology"; and H.-M. for Hertwig's "Text-Book of Embryology of Man and Mammals," translated by Mark.

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Fig. 1. Section through an egg of a Myriapod (Geophilus), showing the nodal thickenings (*n. t.*) in the act of migrating towards the periphery of the egg. See K. & H., Fig. 449.

2. *Free Migration of Amœboid Bodies.* This process differs from the preceding in that the migrating bodies are not connected together. It is characteristic of mesenchyme. I know that Dreyer ('92, Jena. Zeitschr., XXVI. 359) and Sedgwick ('94, Quart. Jour. Micr. Sci., XXXVII.) insist that the cells of mesenchyme, which are usually considered unconnected like so many amœbæ, are really nodal thickenings in an extensive mesh-work or foam-work, the intervening fluids being the, in some places confluent, vacuoles. Wherever mesenchyme has this structure, its migrations belong to the preceding class. But I believe there still remains a considerable residuum of cases falling under this head.

This process is capable of division into two subprocesses; viz. (*a*) migrating of mesenchyme out of a protoplasmic layer in order to become free, and (*b*) migrating through fluid-filled spaces. Both these processes are illustrated in Figure 2. Further illustrations will be found in K. & H., Figs. 102, 103, 170, 175–180, 182, 186, 188–190, 207, 285, 559, 596–598, 628, 698, 733, 809, and M., Figs. 121, 234, 239.

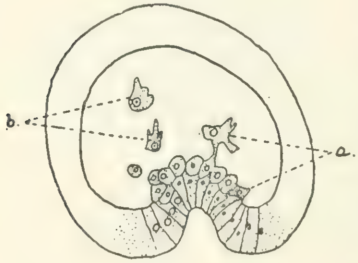

FIG. 2.

The migratory processes named below are of subordinate rank to Nos. 1 and 2. But, being fairly well marked and of considerable importance, it is convenient to treat them as co-ordinate.

We may distinguish, first, movements of mesenchymatous elements towards and from each other, and, secondly, movements with reference to other protoplasmic masses.

3. First among the former we recognize the *aggregation of migratory protoplasmic bodies*, and here we may distinguish three sub-classes according to the form of the resulting body.

*a.* First we have the *aggregation of mesenchyme into a body with a chiefly linear dimension*, — the formation of a thread, cord, or tubule.

Examples of this process in Invertebrates are seen in the formation of the kidney of Lamellibranchs, which seems to be laid down as a cord-like aggregation of mesenchyme, and in that of the thread of the yolk glands

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Fig. 2. Section of Holothurian larva showing mesenchyme migrating out of a layer at *a*, and through a fluid-filled space at *b*. From H.-M., Fig. 109.

of Turbellaria according to Iijima (Zeitschr. f. wiss. Zool., XL. 455). Among Vertebrates, we have the observations of Paterson, (Figure 3,) according to which the sympathetic nerve arises by the aggregation of mesenchymatous elements into a strand; of His, who affirms the origin of the spinal and the olfactory ganglia from migrating cells; and of various authors, who make blood capillaries and lymph vessels arise by this process (cf. M., pp. 217, 413).

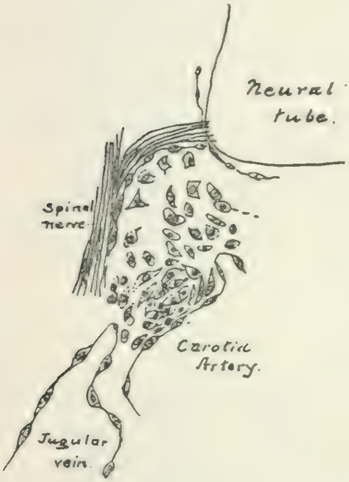

FIG. 3.

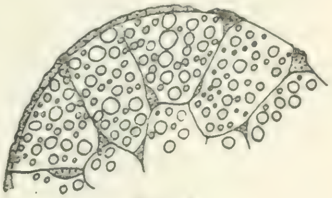

FIG. 4.

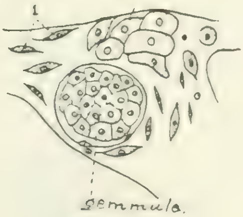

FIG. 5.

*b.* Next we must consider the *aggregation of mesenchyme into a superficially extended body,* — the formation of a layer. This process does not seem to be very common; one example is seen in Figure 4.

*c.* As the last of these processes of aggregation we have the case of *aggregation into a mass.* This wide-spread ontogenetic process may be illustrated by the formation of gemmules in a marine sponge (Figure 5). Other examples are found in the formation of the adductor muscles of

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Fig. 3. Cross section of a rat embryo in the upper thoracic region, showing the development of the sympathetic nerve (between spinal nerve and carotid artery). From A. M. Paterson, '91, Trans. Roy. Soc. Lond., Pl. XXII. Fig. 4.

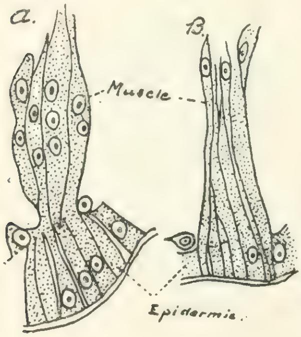
Fig. 4. Later stage of the embryo shown in Figure 1. The migrating protoplasm has aggregated itself into a layer at the surface of the embryo. See K. & H., Fig. 449.

Fig. 5. Section of a marine sponge (Esperella), showing a gemmule, a mass of aggregated mesenchyme which is about to produce a gemmule (1′), and migrating, not yet aggregated mesenchyme (1). After H. V. Wilson ('94, Jour. of Morph., IX. Pl. XIV.).

Lamellibranchs, the muscles of the foot of Gastropods (K. & H., Fig. 556, *s. m.*), and the lymph glands and spleen of Vertebrates (M., p. 414).

The reverse process to the aggregation of mesenchymatous cells is their *Dispersal*, and this has probably been brought about by the opposite cause to that producing aggregation. Since, however, this is a process taking place in a protoplasmic *mass*, its consideration must be deferred. (See page 194.)

We have been considering the different forms into which mesenchymatous elements aggregate themselves in the formation of one body; it now remains to consider the processes taking place between mesenchyme and other protoplasmic bodies. Of these processes I recognize at present four, viz.: the attachment of mesenchymatous cells to a body, following their migration thither; the encapsuling and interpenetration by a mass of mesenchyme; transportation by mesenchyme; and absorption by mesenchyme.



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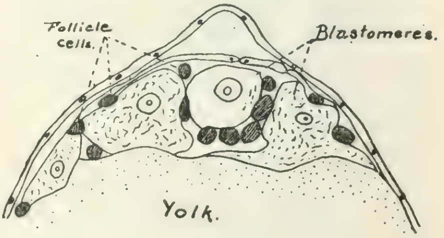

FIG. 7.

4. *Attachment of Mesenchyme* to another body. This process occurs in the union of the muscles of Lamellibranchiata, Annelida, Crustacea, and Bryozoa (Figure 6) to the hard parts of these animals, and of tendon to bone, in Vertebrates.

5. *Investment and Interpenetration, by Mesenchyme,* of a mass — either some other organ of the body or a foreign substance, like a parasite — is a not uncommon process. Especially marked is this process in the Tunicata (Figure 7), where migrating follicle cells encapsule and finally

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Fig. 6. Sections through the body wall of the Bryozoan, Paludicella; (*a*) young, (*b*) adult; illustrating the process of attachment of mesenchymatous muscles to the cuticula.

Fig. 7. Section of the germ disk of Pyrosoma, showing migrating follicular cells surrounding the blastomeres. (See K. & H., Fig. 771.)

penetrate between the blastomeres, so that it is difficult to tell which part of the embryo has been derived from the egg and which part by immigration. Compare the origin of the cutis in Echinoderms (K. & H., Fig. 195), in Mollusca (K. & H., Fig. 686), and in Vertebrates (M., Fig. 306), and of the intestinal and vascular musculature of Vertebrates (H.-M., Fig. 185).

All of these processes have this in common, that mesenchyme migrates to an organ — vessel, layer, or mass — and applies itself closely to it, sometimes even penetrating into the substance of the organ.

6. *Transportation by Mesenchyme* has hitherto been observed in but few cases. The most remarkable instance of this process is found in the Doliolidæ, where the buds produced from a stolon are transported over half the length and half the circumference of the body by means of mesenchyme cells, and are finally deposited, in very regular order, on the appendage of the budding individual. (Figures 8 and 9.) By similar means, apparently, one end of the funiculus of the Bryozoan Cristatella is transported from the dorsal to the ventral surface of the corm, as I have attempted to show elsewhere. (Bull. Mus. Comp. Zoöl., XX. 142.)

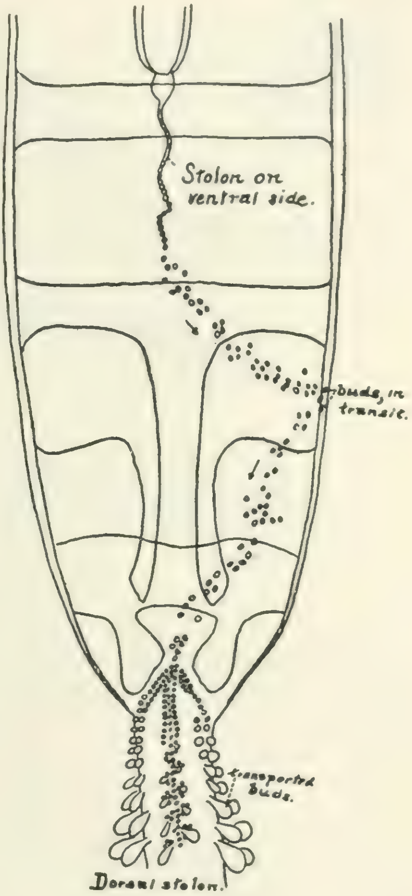

FIG. 8.

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Fig. 8. Dorsal view of the posterior part of a large Doliolum "nurse." Shows the buds being transported from the ventral to the dorsal (and posterior) stolon. (See K. & H., Fig. 830.)

7. *Absorption by Mesenchyme.* Only of late years have we come fully to appreciate the great rôle played in ontogeny by the devouring capacity of mesenchyme. It is now fully established that such migratory protoplasmic bodies — phagocytes — are the most important agent in the degenerative processes which larvæ undergo in their metamorphoses.

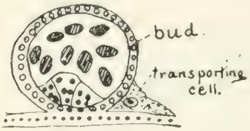

FIG. 9.

This is well shown in Insects (Figure 10), in Bryozoa probably, in Ascidians, and in the frog.

The secreting activity of mesenchyme has already been classed under general processes. No doubt mesenchymatous cells perform various other functions in the body besides transportation, digestion, and secretion, but these either have little effect on the form or concern only histogenesis.

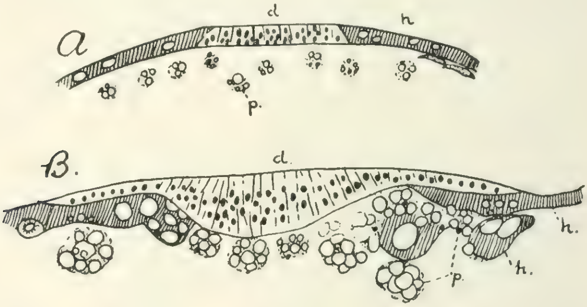

FIG. 10.

## II. ONTOGENETIC PROCESSES OCCURRING IN ELONGATED PROTOPLASMIC BODIES — FIBRES, THREADS, CORDS, TUBULES.

Falling under this head we may recognize, first, certain general changes due to growth, such as increase in length or in thickness. These may affect either the whole body or its parts, and may lead to a diminution or increase in size.

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Fig. 9. Section through the transported bud of Dolchinia, showing the amœboid transporting cell. (See K. & H., Fig. 839.)

Fig. 10. Sections through the abdominal imaginal disks of the hypodermis of Musca. *A*, from the larva. *B*, from the young pupa. In *B* the phagocytes (*p.*) are in the act of devouring the larval hypodermis (*h.*), which is replaced by the superficial growth of the imaginal disk (*d.*). K. & H., Fig. 530.

We may recognize, in the second place, certain processes which concern the *direction* which the elongated body takes and its *relation* to other bodies of the same or of a different kind. This latter group is the only one which requires further analysis and illustration. Vacuolization of cords, such as occurs in blood-vessels, will be considered in Section IV.

In this section we may consider four processes: (1) tropic processes, including the turning of elongated bodies towards or from any object; (2) the splitting of such bodies; (3) their anastomosis; and finally (4) their fusion with other organs.

1. *Turning of Elongated Protoplasmic Bodies towards or from an Object.* This is a process which has long been recognized by botanists as occurring in roots and stems, and as being a response to a stimulus coming from outside the organism. Also among hydroids the position of stolons and hydranths is often clearly determined by external stimuli. Of organs inside of the body, the determination of the direction of growth of nerves has been referred by Herbst to the action of a stimulus supplied by the organ towards which the nerve grows. Other examples of this process are not rare. I will cite a few. Herbst has already referred to the case in Turbellaria where unicellular glands of mesenchymatous origin send out long processes (the necks), which gain their appropriate connections with the other organs. So, too, the shell-gland of Crustacea, which arises from an aggregation of mesenchyme (K. & H., p. 377) secondarily sends out a stalk which makes connection at the appropriate place. The principal blood-vessels of Vertebrates arise in the area vasculosa and subsequently grow into the embryo, following certain prescribed paths (M., pp. 215, 216). From these vessels others in turn bud out, progressing towards their destined organs. According to Field ('91, Bull. Mus. Comp. Zoöl., XXI. 222), the pronephric duct of Amphibia, arising in mesoderm, grows at its posterior end, secondarily fusing with the cloaca. Again, the tubules of the metanephros, according to some authors, bud out of the blind end of the ureter, and in their further growth hit exactly the independently formed Malpighian capsules lying in the mesenchyme. In all these cases we have the elongating body clearly turning towards the object with which it is destined to unite.

Even under some abnormal conditions we have this process taking place; for instance, when a parasite lodges in any organ of a Vertebrate, new vessels are formed, which grow out towards the source of irritation. (Cf. Roux, '81, Der Kampf der Theile, pp. 150, 151).

2. *Splitting of an Elongated Protoplasmic Body* (cord or tubule). We may recognize here two sub-processes: (*a*) splitting at the tip, and (*b*) splitting along the whole length.

*a.* As is well known, nerves grow out as blunt stalks which repeatedly divide at their ends. Paterson has shown that some of the spinal nerves split at the somato-splanchnic angle, as shown in Figure 11. His ('88, Arch. f. Anat., Jahrg. 1887, p. 376) shows in many cases that the splitting takes place where the end of the growing nerve strikes a rigid organ. Thus, he says, when the third branch of the trigeminus strikes Meckel's cartilage, it divides into the ramus lingualis and the ramus mandibularis; and when the hypoglossal meets the jugular vein, it divides into its descending and lingual branches. The way in which the rigid organs act to produce splitting is thus explained by His. Pre-existing resistant objects may be considered as the "Motivs" of division; for as a nerve

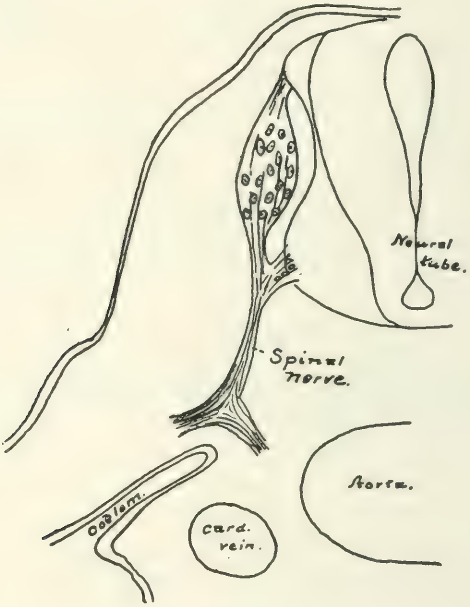

Fig. 11.

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Fig. 11. Cross section of a mouse embryo in the lumbar region, showing the splitting of the spinal nerve at the upper angle of the cœlom. After Paterson, '91, Trans. Roy. Soc. London, CLXXXI., Fig. 5.

stem strikes a cartilage or a vessel, its fibres are bent in different directions and the stem divides. The resisting objects are thus considered by His to act in a mechanical, i. e. *direct* way. The results are, however, equally explicable by the response-to-stimulus theory.

The splitting which occurs at the blind ends of developing blood-vessels and excretory tubules, and the repeated divisions of many glands — salivary gland (M. Fig. 334), liver, and lungs (M., Fig. 445) — are examples of this process. Other cases are found among Invertebrates, as, for example, the tentacles of many Cnidaria (K. & H., Figs. 27, 31), "roots" of Sacculina, and liver branches of Limulus (K. & H., Fig. 338).

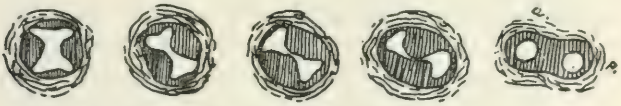

FIG. 12.

*b.* The second case, that of division of a tubule throughout its entire length, is illustrated in the development of the segmental duct in some Vertebrates, and in the separation of aorta and pulmonary artery. (Figure 12).

3. *Anastomosing*, or the process of fusion of similar threads, thus forming a network, is of wide-spread occurrence. It is exemplified in the development of nerves (Figure 13) and blood-vessels in Vertebrates, and in some glands, especially the vertebrate liver.

4. *Fusion with other Organs.* The process of fusion of diverse organs will be studied in greater detail in other sections of this paper. It occurs, for instance, at the close of the process of growth of the neck of a mesenchymatous gland (or other independently arising tubule) towards its insertion.

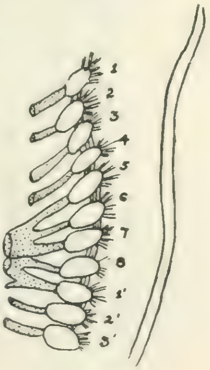

FIG. 13.

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Fig. 12. Sections at different levels through the cardial aorta of a human embryo of 11.5 mm. The lowest section is at the left; the highest at the right: the separation progresses from above downwards. *a*, aorta; *p*, pulmonary artery. See M., Fig. 293.

Fig. 13. The cervical and three of the thoracic spinal nerves of a human embryo, showing the origin of the thoracic plexus. See M., Fig. 360.

## III. Ontogenetic Processes occurring in Protoplasmic Layers.

The ontogenetic processes occurring in protoplasmic layers may concern one layer only, or two or more layers acting in relation to each other.

The processes which take place in one layer are principally growth processes affecting on the one hand the *area*, on the other the *thickness* of the layer.

$\text{III}^{\text{a}}$. Of the growth processes affecting *area*, we may distinguish ($\alpha$) such as take place in the walls of a hollow sphere or cylinder from ($\beta$) such as take place on a plane or warped surface.

*α.* The areal growth occurring in a hollow sphere or cylinder (sac) may be equal in all the axes or elements of the wall, leading merely to a change of size of the sac; or it may be unequal in the various axes or elements, producing a change in form. It is this latter group which especially interests us, and it will therefore be further analyzed.

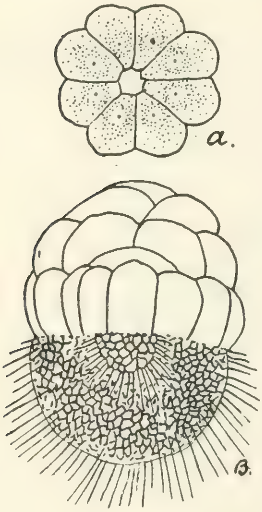

Fig. 14.

1. We may recognize three cases in the differential growth processes occurring in a sac: (*a*) unequal growth in the different axes; (*b*) unequal growth at the poles of the axis; (*c*) unequal growth in the various meridians of the sac.

These three processes deserve illustration.

*a.* By the process of excessive growth in a certain axis we have the ellipsoidal form produced from the spherical; as in the Sycandra larva (Figure 14); in planulæ (K. & H., Figs. 14, 30, 32, 51); in the larvæ of various worms (K. & H., Figs. 144, 158, 159); in the Echinoid blastula (K. & H., Figs. 173, 176); and in the larvæ of some Mollusca (Figs. 542, 576, 593, 596) and Bryozoa (Fig. 702).

*b.* Through unequal growth at the two poles of (e. g. the chief) axis, we have produced such ovoidal forms as planulæ, in which not only is the chief axis elongate, but one pole has grown more than the other. (Figure 15.) By unequal growth at the poles are produced also such

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Fig. 14. Sycandra embryos. *A*, 8-cell stage; *B*, larva. See K. & H., Figs. 2 and 3.

club-shaped pouches as the "club-shaped gland" of the Amphioxus larva (K. & H., Fig. 875).

*c.* Through unequal growth of the different meridians of a spheroidal or cylindrical wall we have produced from the spheroid an apparent flattening on one face, such as occurs, for example, in various cases of "epibolic gastrulation." In Figure 16 this process is illustrated in the spheroidal egg of a Heteropod. (Cf. K. & H., Figs. 66, 541, 738.)

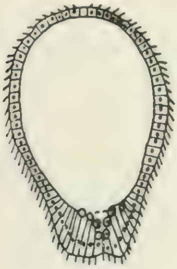

FIG. 15.

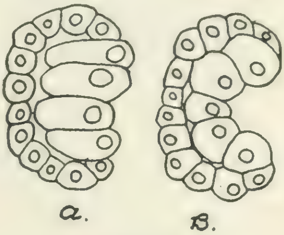

FIG. 16.

By an excess of growth along the meridians of one side of a cylinder we have produced such apparent rotations of the internal organs as occur in Crinoids and Endoprocta. (K. & H., Figs. 218, 732.)

*β.* Let us now consider the unequal areal growth of a part of a bounding layer taken so small that it may be considered as nearly a plane or a warped surface. We shall find that the processes taking place in such a part are among the commonest and most important of all occurring in ontogeny.

This unequal growth may result, either (2) in parts formerly lying in one plane moving into different planes; or (3) in parts formerly lying in one line moving out of that line.

2. It has long been recognized that, when in a layer excessive growth takes place over a restricted area, the result is that the excessively enlarged area can no longer occupy its former territory. Since its periphery remains relatively constant while the included layer increases

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Fig. 15. Section through the planula of Æquorea, to show the greater expanse at one pole than at the other. See K. & H., Fig. 14.

Fig. 16. Sections through young embryos of Firoloides, showing how the condition in stage *B* has been derived from that of stage *A* by greater growth along the meridians on the left than on the right. See K. & H., Fig. 584.

in area, the latter is compelled to fold, producing, according to the point of reference, an elevation above or a depression below the general level.

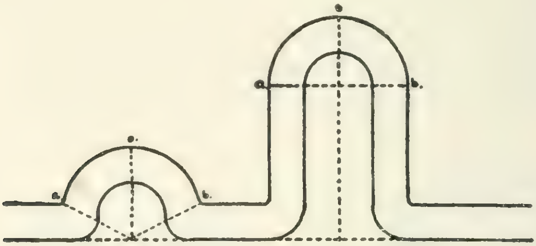

Fig. 17.

So important relatively is the process of folding that it has apparently been regarded by some authors as almost the sole developmental process. How important a rôle it plays is well illustrated in Figure 18, where (excepting the nerve masses and the heart, which are unrepresented) all of the differentiated organs of the squid which at this stage lie in the sagittal plane are represented. And these are seen to have arisen by the foldings of the unilaminar blastoderm which covers the yolk. The connections of the otocyst and the shell-gland with the exterior are now lost, but fin, mantle margins, funnel, and the various appendages of the alimentary tract, as well as the tract itself, are all seen to be arising as foldings of the blastoderm. This view does

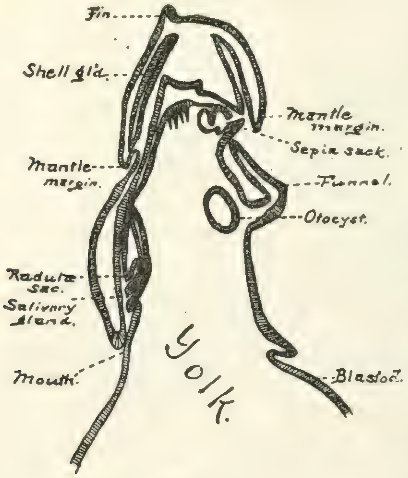

Fig. 18.

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Fig. 17. Diagram representing the process of folding as it occurs in protoplasmic layers. By excessive growth between *a* and *b*, the fold *a o b* is produced.

Fig. 18. Sagittal section of an embryo of Loligo vulgaris, showing the origin of organs through foldings of the blastoderm. From K. & H., Fig. 673.

not include the lateral organs, — eye vesicles, gills, and arms, — which arise in a similar fashion as folds.

Based upon the form of the growing area, two classes of folds may be recognized: —

(*a*). *Pockets,* from a circular area.
(*b*). *Linear folds,* from an elongated area.

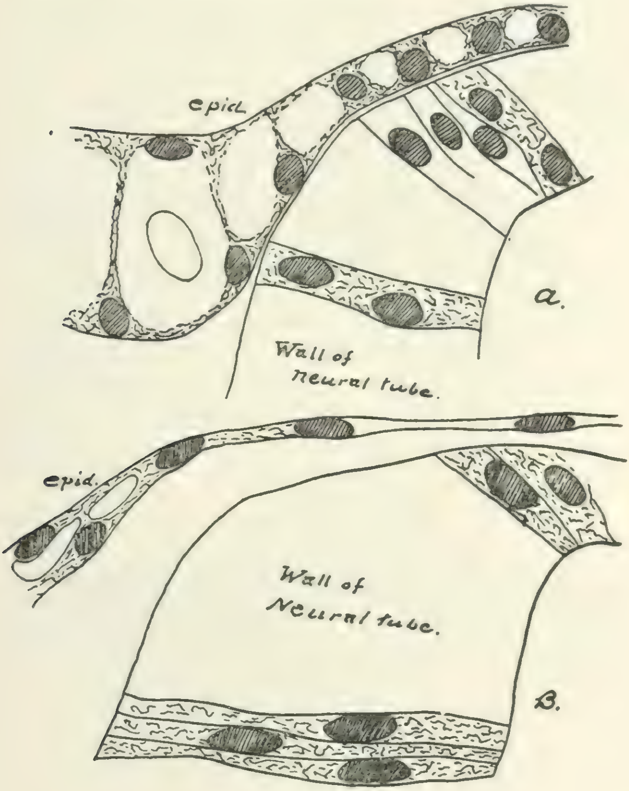

FIG. 19.

Good examples of the formation of pocket folds are seen in many cases of gastrulation, and in the otocyst, shell gland, salivary gland, and sepia sac of Figure 18.

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Fig. 19. Two stages in the development of the epidermis and neural tube of the chick. Both magnified to the same extent. (From W. His, '94, Arch. f. Anatomie, Jahrg. 1894, pp. 74, 76)

Typical linear folds occur in the formation of the neural tube of most Vertebrates, of the lateral line of fishes, and of the atrium of Amphioxus. (K. & H., Fig. 881.)

3. Inequalities of growth in different parts of the layer may take place, so that parts originally lying in a line move out of that line. By this means are produced folds lying in the plane of the layer, — folds comparable to those made by an advancing wave front on entering a bay. Such folds may occur in the *bounding line* of the growing layer, as happens, it is alleged by some, in the overgrowth of the yolk by the blastoderm, — a process by which the crescentic notch is produced on the edge of the blastoderm. Again, such folds may occur in the *midst* of a layer, producing a relative displacement of the points lying in that layer. To this process may be referred the remarkable rotation of the gill slits and mouth of Amphioxus, — the gill slits rotating from the right to the left side of the larva, the mouth from the left side towards the mid-ventral line.

III$^b$. The processes affecting thickness of the layer are of very common occurrence, and are of two kinds, — (4) processes leading to an increase, and (5) those leading to a diminution in thickness. These variations in thickness may be general, extending over a considerable part or the whole of the area under consideration, or they may be restricted to a small part of that area.

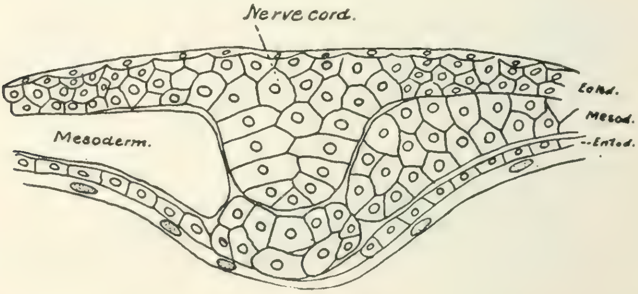

FIG. 20.

4. The process of thickening is illustrated in the lateral walls of the neural tube of Vertebrates (Figure 19), and, localized, in the formation of the neural tube in Teleosts (Figure 20). Other examples are seen in

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Fig. 20. Cross section of the blastoderm of a bony fish (Serranus atrarius) to show the linear thickening of the ectoderm to produce the nerve cord. (From H. V. Wilson, '91, Bull. U. S. Fish Commission, IX. Plate XCV.)

the papillæ which precede the formation of feathers, and in the ingrowing follicles which form hairs.

5. A general thinning of the walls of the organs is found to accompany the development of many Invertebrates. Figure 21 illustrates this fact.

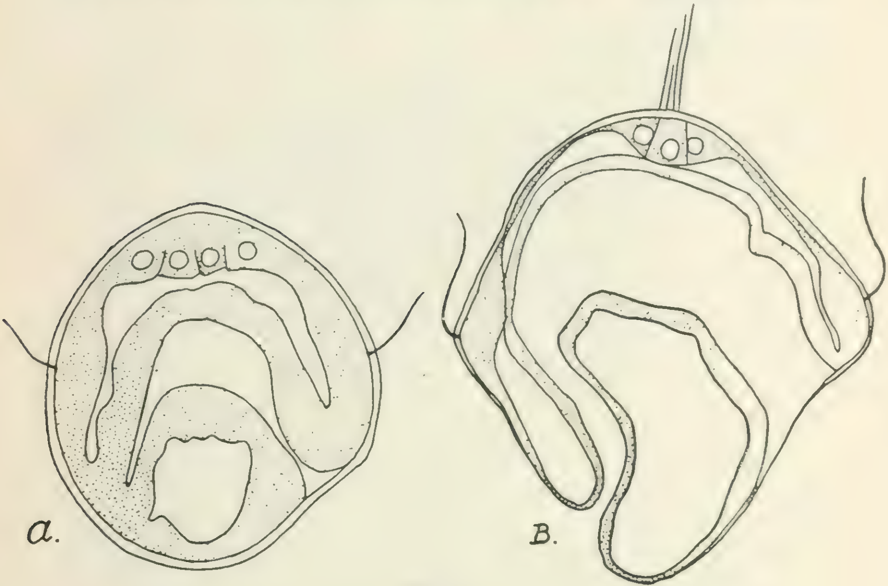

FIG. 21.

In Figure 19 a general thinning of the epidermis is seen in passing from stage $\alpha$ to stage $\beta$. A good example of local thinning is seen in the formation of the ependyma of the roof of the brain and medulla.

The processes of thickening and thinning may go on side by side, as in the formation of the lens of the vertebrate eye (Figure 22), where the outer and inner layers of the lens are at an early stage of nearly equal thickness, but where, in the later stages, the outer layer becomes thin, and the inner layer enormously thick.

III$^c$. Next, we must consider the processes by which a single continuous layer experiences an interruption in its continuity. This may take place (6) by a complete *atrophy* of a part of the membrane, thus forming a hole or rift in it, or (7) by a separating off of a certain piece from the membrane.

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Fig. 21. *A*, younger, and *B*, older Trochopore stages of the annelid Eupomatus uncinatus, seen in sagittal section. Drawn to same scale. Outlines copied from Hatschek, '86, Arb. Zool. Inst. Wien, VI. See also K. & H., Fig. 118.

6. The former process occurs typically in the ontogeny of reptiles, and perhaps of mammals, where the middle of the layer of "primary entoderm" roofing the yolk cavity atrophies, making a great hole in the layer.

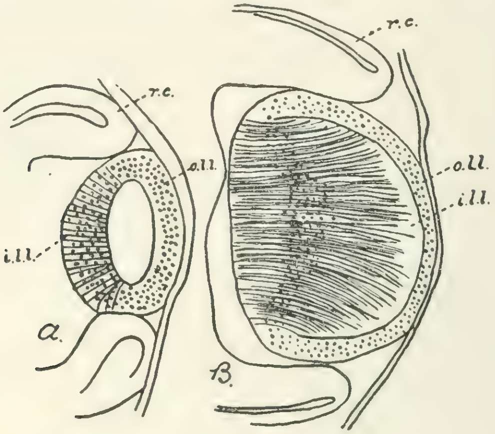

Fig. 22.

7. The latter process is represented in Hatschek's familiar figure of the formation of the neural tube of Amphioxus (Figure 23), where the medullary plate is shown as falling below the general level without the intervention of a fold. Compare the formation of the "body plate" of the Nemertine Lineus, K. & H., Fig. 105, and gastrulation in Apis, K. & H., Fig. 495.

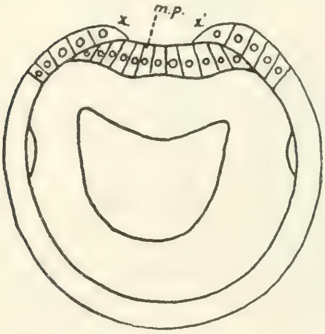

Fig. 23.

III$^{\text{d}}$. Finally, we must consider the important processes involving two or more protoplasmic layers. Such layers may move either towards or from each other. We will here consider only the former group of cases.

8. The mutual approach and fusion of layers may be called *con-*

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Fig. 22. *A*. Section of eye of chick embryo on third day. (See M., Fig. 413.) *B*. Section of eye of rabbit embryo, 13 days old. (See M., Fig. 409.) *i. l. l.*, inner lens layer; *o. l. l.*, outer lens layer; *r. c.* retinal cup.

Fig. 23. Section across an Amphioxus embryo, showing the medullary plate, *m. p.*, which has sunk below the level of the ectoderm, producing a discontinuity in the latter. From H.-M., Fig. 69.

*crescence.* We may distinguish three sub-processes under this head, depending upon whether (*a*) the concrescence takes place along the free margins of layers, or (*b*) along their surfaces, or, finally, (*c*) along the edge of folds. This concrescence is usually quickly followed by other processes which we will consider later.

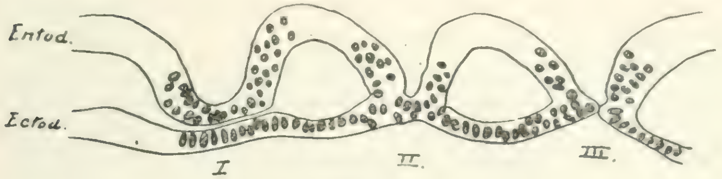

FIG 24.

*a.* The concrescence of layers by their free edges is illustrated in the cases of the growing together of the free edges, $x$ and $x'$, of the ectoderm in the Amphioxus embryo at a stage a little later than that shown in Figure 23. (K. & H., Fig. 504.)

*b.* The concrescence of layers flatwise is illustrated in the formation of the vertebrate mouth when the anterior end of the entodermal sac comes in contact with the ectoderm. Likewise in the formation of the gill slits of Vertebrates the broad bottoms of the entodermal sacs move to the ectoderm. (Figure 24, I, II.)

*c.* Concrescence along the edges of two folds is perhaps the commonest of these three forms of concrescence. It is that by which in Vertebrates the neural tube is closed (Figure 25, *A*, *B*, *C*); ectodermal

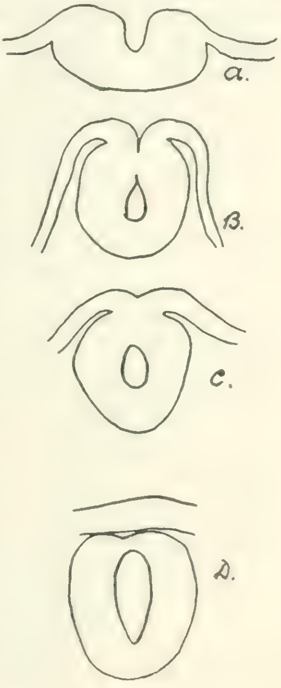

FIG. 25.

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Fig. 24. Part of a frontal section through an embryo of Acanthius vulgaris, of about the stage of Balfour's Stage I. Shows 3 stages in the formation of the gill slit, I, II, illustrating *concrescence* of layers flatwise; III, *perforation*. Original. From a preparation kindly lent me by Mr. H. V. Neal.

Fig. 25. Cross sections through the neural tube of embryo frogs of different ages, showing the concrescence of the lips of the medullary groove (*A*, *B*, *C*), and (*D*) the final separation of the upper and lower layers of the fold. After H. H. Field, '91, Bull. Mus. Comp. Zoöl., XXI. No. 5.

pockets, like the lens and otocysts, become transformed into closed sacs; and grooves, like those of the lateral line, become transformed into canals. In Invertebrates also this process is a very common one, being exemplified in the closure of the blastopore, in the closure of the amniotic cavity in Insects (K. & H., Figs. 474, 475, 484), and in the formation of optic and otic vesicles generally (K. & H., Figs. 377, 630, 681–683).

The end of the process of concrescence proper is a *fusion* of the two concrescing layers, whether the concrescence is occurring along free edges, flatwise, or along the edges of folds. (Fig. 25, *C*, Fig. 24, II.)

9. Frequently this process is followed by another one; viz. the *perforation* of the fused layers (Fig. 24, III), or the *separation* of the upper and lower components of the folds when two folds have been concrescing (Fig. 25, *D*). By means of *perforation* the two spaces separated by the fused walls are put into communication with one another. By means of *separation* a pocket becomes a closed sac, and a groove becomes a tube.

## IV. ONTOGENETIC PROCESSES OCCURRING IN PROTOPLASMIC MASSES.

These may be classed into three categories according as the most *prominent* change produced is ($\text{IV}^{a}$) in volume, ($\text{IV}^{b}$) in form, or ($\text{IV}^{c}$) in number of masses.

$\text{IV}^{a}$. 1. Under the first group are included changes produced by *growth* which is not uniform in all parts. Thus the growth may be prevailingly along one axis, by which means a cylindrical mass is derived from a spherical one (embryos of Dyciemidæ, K. & H., Fig. 99), or it may be excessive at one pole (gemmules of sponges, H. V. Wilson, '94, Jour. of Morphol., IX., Pl. XVI.), or along one meridian. Again the growth may be more localized, being confined to a small area or to a line; as, for instance, in the case of the mesodermal core of the appendages of Arthropods (K. & H., Fig. 371), and of Vertebrates (Figure 26, "limb-bud"). By

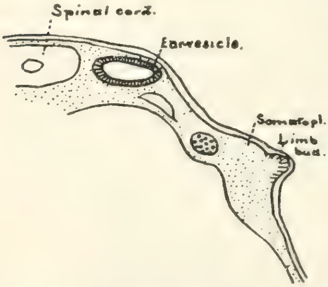

FIG. 26.

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Fig. 26. Cross section through embryo of a Teleost, Fundulus, showing origin of the pectoral limb-bud as a solid outgrowth of the somatopleure. After E. R. Boyer, '92, Bull. Mus. Comp. Zoöl., XXIII. No. 2, Fig. 58.

this process of localized solid growths the principal differentiations of Phanerogams occur.

IV$^{b}$. 2. An important change of form of a protoplasmic mass may occur independently of growth by a *rearrangement of the nuclei* of the mass.

Good examples of this process are found in the development of the larva of Lucernaria (Figure 27); in the development of Ctenophores (K. & H., Fig. 67); and in the changes of form occurring in the "ectodermal basal plate" of Salpa (an apparent syncytium), according to the figures of Heider ('95, Abh. Senckenberg. naturf. Ges., Bd. XVIII. Figs. 32, 40, 41). In so far as this process involves the migration of nuclei, it is clearly closely related to Process I. 1.

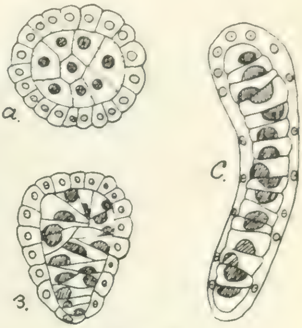

FIG. 27.

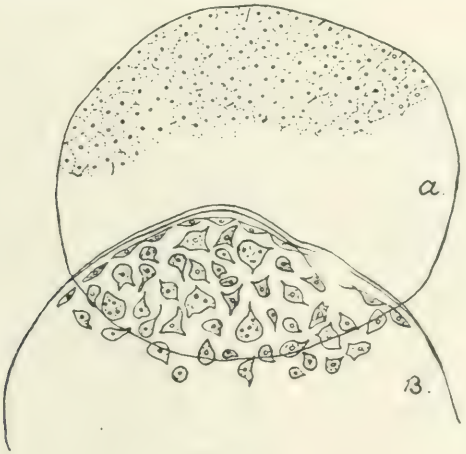

FIG. 28.

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Fig. 27. *A*, *B*, *C*, are three successive ontogenetic stages of Lucernaria. The transformation from stage *B* (36 nuclei in the section) to stage *C* (33 nuclei in the section) is due to a rearrangement of the nuclei. See K. & H., Fig. 49.

Fig. 28. *B*, dispersal of elements of the gemmule *A*, which was formed, as illustrated in Figure 5, by the aggregation of similar mesenchymatous elements. This process precedes the development of the gemmule into a larva, and accompanies the imbibition of water by the gemmules. After H. V. Wilson, '94, Jour. of Morphol., IX., Plate XVI.

3. Another way in which the mass changes form without growth is by *vacuolization.* Through vacuolization there arise, e. g., the blastula in many eggs, the secondary body cavity in many Invertebrates (K. & H., Fig. 131, 689), and in Bryozoa the cavities of the bud. This process of vacuolization, which I introduce for convenience at this place, is not confined to masses. Many cords by vacuolization (canalization) become tubules, and many layers become divided into two. Of vacuolated *cords,* I need refer only to the formation of capillaries in Vertebrates and of nephridia in Invertebrates; of vacuolated *layers,* to the origin of the cœlom in most Vertebrates. In all cases, the acquisition of a mass of water at the centre causes a rearrangement of the nuclei.

4. Perhaps this is the most fitting place to mention the process of *Dispersion* of elements, which occurs not only in bodies originally formed by aggregations of mesenchymatous elements (Fig. 28), but also in *layers* having an epithelial origin, e. g. the ectoderm of Distomum. (K. & H., Fig. 88.)

IV$^c$. The remaining processes occurring in protoplasmic masses are of such a nature as to alter the *number* of masses. We can distinguish, correspondingly, two classes: the first including such as have to do with the formation of two masses from one, through division; the second including those which have to do with the union of two masses into one. The first, then, are *division* processes; the second, *fusion* processes.

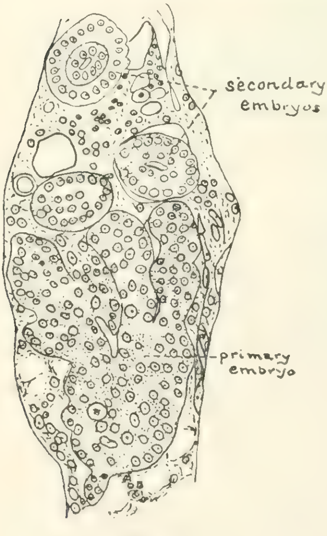

Fig. 29.

5. Under the first head we may include the process of *constriction,* by which two more or less independent masses arise from one. An illustration of this is found in the case of embryonic fission described for some Bryozoa by Harmer (Figure 29). Closely allied to this is the process of sloughing off of a part of the body in metamorphosis, one of the most striking instances of which is shown in

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Fig. 29. Section through a brood chamber of Crisea eburnea, showing the constricting off of secondary embryos from the primary embryo. After Harmer, '93, Quart. Jour. Mic. Sci., XXXIV., Plate XXIII. Fig. 11.

Sacculina, where the thorax and abdomen are thrown off, the head alone persisting to complete the metamorphosis.

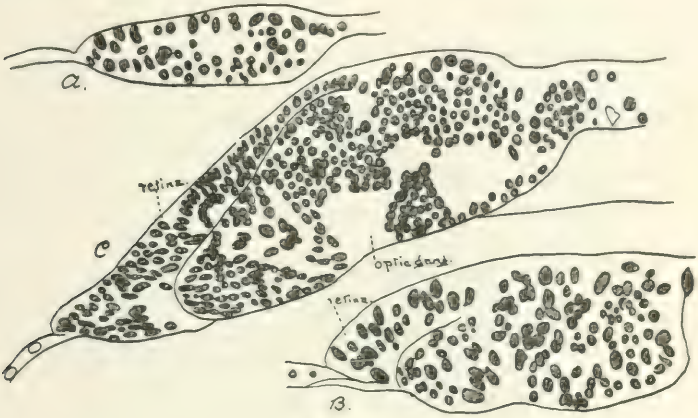

FIG. 30.

6. Another division process is that of *splitting* of the mass. This is illustrated by the case of the optic mass of the lobster (Figure 30), which splits into an outer and an inner part. Compare the origin of the nervous system of Peripatus, K. & H., Fig. 442, B.

7. Under the second head, *fusion* of contiguous masses, we may place such cases as that of the union of independently arisen ganglionic masses, such as Morgan describes for the Pantopod, Pallene (Figure 31).

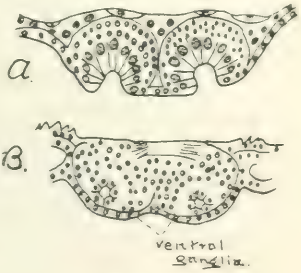

FIG. 31.

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Fig. 30. Sections through three stages in the development of the compound eye of the lobster after G. H. Parker. In *B* and *C* the mass is seen to be splitting into the retina and optic ganglion. See K. & H., Fig. 263.

Fig. 31. Ventral part of sections across Pallene embryos. *A*, earlier stage, showing the paired neural invaginations; *B*, later stage, ganglia fused. See K. & H., Figs. 409, 410.

## Recapitulation and General Remarks.

We may now, in recapitulation, arrange in tabular form the differential processes which we have recognized.

- I. Processes occurring in *mesenchyme.*
    - 1. Migration of nodal thickenings, p. 175.
    - 2. Free migration of amœboid bodies, p. 176.
        - *a.* from a layer.
        - *b.* through fluid-filled spaces.
    - 3. Aggregation of mesenchyme, p. 176.
        - *a.* into a thread.
        - *b.* into a layer.
        - *c.* into a mass.
    - 4. Attachment of mesenchyme, p. 178.
    - 5. Investment and interpenetration, p. 178.
    - 6. Transportation, p. 179.
    - 7. Absorption, p. 180.
- II. Processes occurring in protoplasmic *threads* or *tubules.*
    - 1. Tropism, p. 181.
    - 2. Splitting, p. 182.
    - 3. Anastomosing, p. 183.
    - 4. Union with other organs, p. 183.
- III. Processes occurring in protoplasmic *layers.*
    - III$^a$. Processes affecting *area.*
        - *α.* Processes occurring in the wall of a sac.
            - 1. Excessive growth of particular parts, p. 184.
                - *a.* along one axis.
                - *b.* at one pole.
                - *c.* along one meridian.
        - *β.* Processes occurring in a plane or warped surface.
            - 2. Formation of perpendicular folds, p. 185.
                - *a.* Pocket folds.
                - *b.* Linear folds.
            - 3. Formation of folds in the plane of the area, p. 188.
    - III$^b$. Processes affecting *thickness.*
        - 4. Thickening, — general or local, p. 188.
        - 5. Thinning, — general or local, p. 189.
    - III$^c$. Processes affecting *continuity.*
        - 6. Atrophy, p. 190.
        - 7. Detachment of a piece from a layer, p. 190.

- $III^d$. Processes affecting *two or more layers.*
  - 8. Concrescence, p. 191.
    - *a.* of free edges.
    - *b.* of surfaces.
    - *c.* of edges of folds.
  - 9. Perforation, p. 192.
- IV. Processes occurring in protoplasmic *masses.*
  - $IV^a$. Effecting especially change of *volume.*
    - 1. Excessive growth of particular parts, p. 192.
      - *b.* general.
      - *c.* local.
  - $IV^b$. Effecting especially change of *form.*
    - 2. Rearrangement of nuclei, p. 193.
    - 3. Vacuolization, p. 194.
    - 4. Dispersion of elements, p. 194.
  - $IV^c$. Effecting especially change in *number.*
    - 5. Constriction, p. 194.
    - 6. Splitting, p. 195.
    - 7. Fusion, p. 195.

The processes here ennumerated may be for the most part grouped under three general heads: —

I. Taxic processes.
II. Tropic processes.
III. General growth processes.

Under *Taxic Processes* I include such as are accompanied by free migration of protoplasmic bodies, or by the flowing of protoplasm from one part of the whole body to another part.

Under *Tropic Processes* I include such differential growth processes as result in a turning of protoplasmic bodies (threads or folds) towards one another or towards another protoplasmic body.

By *General Growth Processes* I mean those differential growth processes which are not included under tropic processes.

To the category "taxic processes" may be provisionally assigned Nos. I. 1, 2, 3, 4, 5, and 6; III. 4 (in part) and 5 (in part), 7 (?), 9; IV. 2, 4, 5, 6, 7.

To the category "tropic processes" may be assigned Nos. II. 1, 2, 3, 4; III. 8, 9.

To the category "general growth processes" may be assigned Nos. III. 1, 2, 3, 4 (in part) and 5 (in part), 6; IV. 1 and 3.

It will be noted that No. I. 7 (absorption by mesenchyme) is not assigned to any one of the three categories; and that certain other processes (III. 7, Detachment from a layer; II. 2, Splitting; III. 4 and 5, thickening and thinning of a layer; and IV. 3, Vacuolization) are of so doubtful a nature that, although assigned to the special categories, this assignment can be regarded as provisional only.

The process of absorption does not readily fall into one of the three categories, and at the same time it does not seem worth while to erect a special category for it.

As for the doubtful cases, the doubt is not whether they are referable to one of these categories, but rather in knowing in which one to place them.

Regarding the three general categories, it has long been recognized that taxic and tropic processes are responses to stimuli. It has not been so generally recognized that all growth processes are such. A moment's consideration will, however, make this probable.

Let us consider for a moment what it is that controls differential growth, — What makes one part of a membrane grow faster than another, causing a folding of that part?

Inequality of growth is clearly not due to inequality of food supplied, since folds arise in uniformly nourished membranes, — bathed, that is to say, uniformly by the nutritive fluids. It must therefore be due to inequality of the activities which lead to growth; namely, the taking in of food and its assimilation, and the imbibition of water. Now it is our fundamental assumption that activities of all sorts, including ingestion and imbibition, are responses to stimuli. In so far, then, as differential growth is dependent upon the inequality of these activities in different parts of the membrane, it is dependent upon stimuli acting upon that membrane.

Whenever the activities are diverse in the different parts of a membrane, it must be either that the stimulus applied to the different parts is diverse, or, if not, that the protoplasm is diverse in its different parts, for what the result shall be depends upon two factors, — the quality of the stimulus and that of the protoplasm.

Let us now consider somewhat more in detail the taxic and tropic processes. As is well known, the stimuli which control these movements result either in migration towards the source of the stimulus or away from it, so that positive or negative taxis or tropism occurs. In ontogeny it is often impossible to say where the source of stimulation is, and therefore whether the tactic or tropic movements are + or —. Certain criteria may, however, be employed in some cases to determine this. Thus, where many migratory bodies move towards a common point, or where a thread or tubule makes its way to a distant point, we may believe that a positively tropic stimulus is exercised by that point. Also, where two similar parts move towards each other, it is probable that a + stimulus is exerted by both; where, on the other hand, they mutually withdraw, it is probable that a mutual negative stimulus emanates from both.

With these criteria in mind we may classify some of the taxic and tropic processes as + or —, and this I have attempted to do in the following table: —

PROBABLE RESPONSES TO POSITIVE STIMULI.

*Taxic.*

I. 3. Aggregation of mesenchyme.
I. 4. Attachment of mesenchyme.
I. 5. Investment and interpenetration.
I. 6. Transportation.
III. 4. Thickening of a layer (when due to flowing towards one point).
IV. 7. Fusion of masses.

*Tropic.*

II. 1. Turning of thread.
II. 3. Anastomosing.
II. 4. Union with other organs.
III. 8. Concrescence.

PROBABLE RESPONSES TO NEGATIVE STIMULI.

*Taxic.*

I. 2, *a*. Migration from a layer.
III. 4. Thinning of a layer (when due to flowing of the protoplasm from a point).
III. 9. Perforation.
IV. 4. Dispersal of elements.
IV. 5, 6. Separation of masses.

PROBABLE RESPONSES TO EITHER + OR — STIMULI.

I. 1. Migration of nodal thickenings.
I. 2, *b*. Free migration of amœboid bodies.
IV. 2. Rearrangement of nuclei.

It is not too much to believe that the foregoing hypothetical interpretation of the ontogenetic processes lies within the possibility of experimental test. Just as the control of the migration of amœboid bodies in the adult has been undertaken with success, so may we hope to control the tropic and aggregation phenomena of ontogeny. By *experiment* alone can the causes of the developmental processes be determined.

CAMBRIDGE, Mass., May 1, 1895.

# No. 7. — *The Early Embryology of Ciona intestinalis, Flemming (L.).*[1] By W. E. Castle.

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## I. INTRODUCTION.

So long ago as 1866, Kowalevsky wrote, "Die Entwicklungsgeschichte der Ascidien wurde schon vielfach studirt." If this statement was true then, it is doubly so now, for the literature of the subject has since that time multiplied many fold. Nevertheless there still remain many unsettled questions regarding the embryology of the Tunicates. Concerning so fundamental a point as the derivation of the primary germ layers in the embryo, quite contradictory opinions have been expressed within the last ten years by observers of world-wide reputation.

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[1] Contributions from the Zoölogical Laboratory of the Museum of Comparative Zoölogy at Harvard College, under the direction of E. L. Mark, No. LII.

I undertook the inquiry, the results of which are recorded in the following pages, in the hope of being able to throw light on this disputed question by the study of other forms than those which had been most carefully examined, and by the application of new methods to the problem. A short experience convinced me that the only method which could yield positive conclusions was that of cell lineage, a method which has been applied so successfully to the study of annelid and molluscan embryology by a number of observers, and had already been employed to a limited extent in the study of ascidian embryology by Van Beneden et Julin ('84), Seeliger ('85), and Chabry ('87).

It soon became clear to me that some of the conflicting statements made by my predecessors arose from errors on their part due to incorrect orientation of certain stages. The nature of these errors I have fully explained in a preliminary communication (Castle, '94). A further study of the embryonic history, cell by cell, through the periods of cleavage and gastrulation, and even down to the differentiation of the several larval organs, has led me to conclusions somewhat at variance with those of earlier investigators regarding the origin of the primary germ layers and the organs derived from them. One of the most important of these conclusions is that the mesoderm of Ascidians — and probably also that of Amphioxus and the Vertebrates — is derived in part from the primary entoderm and in part from the primary ectoderm. The grounds on which this conclusion rests are set forth in the later portions of this paper; in the earlier part of the paper I have recorded some observations on the maturation and fertilization of the ascidian egg.

It gives me pleasure to acknowledge in this place my very great obligations to Professor E. L. Mark for direction and kindly criticism of my entire work. My best thanks are also due to Dr. Alexander Agassiz, in whose laboratory at Newport the material for my studies was chiefly collected, and to Colonel Marshall McDonald for numerous courtesies extended to me at the United States Fish Commission Station at Wood's Holl.

## II. MATERIAL, LIFE HISTORY.

The material for this study was collected in the months of August and September of two successive seasons, 1893 and 1894. The species employed seems to be, beyond question, the Ciona intestinalis of Flemming, a classical object of study on the other side of the Atlantic. It was made the subject of an extensive monograph by Roule ('84); its larval history has been studied by Kowalevsky ('66 and '71) and by Willey ('93); its cleavage stages by Samassa ('94); its fertilization stages by Boveri ('90); and the formation of its egg envelopes by Fol ('84). Loeb ('91) also has employed it in certain physiological investigations. The specimens which I collected at Newport answer fully to Roule's detailed descriptions of the species. The large size (8–10 cm. long) attained by individuals at Newport under favorable conditions confirms Roule's conjecture that the forms described from the United States as Ascidia ocellata by Louis Agassiz, as A. tenella by Stimpson ('52), and as Ciona tenella by Verrill ('71) were only small-sized individuals of Ciona intestinalis.

Specimens were obtained by me from two different localities just within the entrance of Narragansett Bay. The animals were usually found adhering to the under side of stones at a depth of from a few inches to a few feet below low-water mark. Upon removal to the laboratory they were carefully washed and placed in aquaria whose water was kept fresh by a jet of air. Once a day the water was changed, and the aquaria thoroughly cleaned, to prevent the accumulation of bacteria or other possibly injurious organisms. This painstaking treatment was probably unnecessary, for the animals are very hardy and bear ill-treatment well. For example, I have kept specimens for weeks at a time in small glass aquaria without change of water, and the only signs of misuse which they exhibited were a slight shrinkage in size and a greatly diminished production of eggs, — both symptoms referable to an insufficient food supply.

Ciona, like all other Tunicates, is hermaphroditic, and the number of eggs produced by a single adult individual in the course of a season must be enormous. Often hundreds are deposited in a single night. Under normal conditions each adult individual, during the summer months, lays eggs once in every twenty-four hours, with the regularity of the sunrise.

Korschelt u. Heider ('93, p. 1267) state that in most cases among the Ascidians self-fertilization appears to be prevented by the ripening of the male and female sexual elements at different periods; although in some cases, where the sexual products mature simultaneously, self-fertilization is not excluded. Neither of these statements holds good for Ciona. Although in the adult period it produces both sexual elements throughout the spawning season, and discharges them simultaneously, self-fertilization rarely occurs, — a conclusion to which I have been led by repeated experiments. The most complete series of these experiments will be briefly described.

The observation had been made that an individual accidentally left overnight in an aquarium by itself laid eggs which failed to develop; whereas, when two or more individuals were placed together in an aquarium, all other conditions being the same, the eggs laid developed almost without exception.

### *First Experiment.*

Acting on the suggestion thus offered, I placed together in an aquarium two or three small, clear individuals (evidently young); in another aquarium was placed an equal number of very large-sized (old) individuals. A greater number of eggs was laid by the large individuals, as one would naturally expect, but the eggs in both aquaria were perfectly fertile. This experiment showed that ripe eggs and sperm are produced both by young and by old individuals.

### *Second Experiment.*

Twenty rather large-sized individuals were selected for experimentation and divided into two lots, A and B, of ten individuals each. The animals of each lot were carefully washed and placed in clean glass dishes filled with fresh sea-water. The individuals of lot A (Table I.) were placed each in a separate dish, those of lot B (Table II.) were placed two in a dish. The next morning a careful examination of each aquarium was made to determine what proportion of the eggs laid had been fertilized. The experiment was repeated on five successive days; on the sixth day, as a control experiment, the lots were interchanged, the animals of lot A (Table II.) being paired, and those of lot B (Table I.) isolated. The results for the six days are embodied in Tables I. and II.

Taking an average of the fifty-eight cases in which eggs were laid by isolated individuals (Table I.), we find that 4.8% of the eggs were fertilized. The occurrence on a single day in two cases of fertilization of 90% of the eggs laid makes me suspect that the dishes were not properly cleaned on that day, and that live spermatozoa may have remained clinging to the sides of the dish after the previous day's experiment. If so, and if

TABLE I.—Close Fertilization.

| | Lot A. | | | | | Lot B. | |
|---|---|---|---|---|---|---|---|
| Day. | 1st. | 2d. | 3d. | 4th. | 5th. | 6th. | Total of Cases. |
| 90% fertilized | | | 2 | | | | 2 |
| 25% fertilized | 1 | 1 | | | | | 2 |
| 10% fertilized | | 1 | 1 | | 1 | | 3 |
| 5% fertilized | 1 | 1 | | 1 | | | 3 |
| 4% fertilized | | | | 1 | | | 1 |
| None fertilized | 8 | 7 | 7 | 7 | 8 | 10 | 47 |
| No eggs laid | | | | 1 | 1 | | [2] |
| Total | | | | | | | 58<br>[60] |

Average fertility = 4.8%.

TABLE II.—Cross Fertilization.

| | Lot B. | | | | | Lot A. | |
|---|---|---|---|---|---|---|---|
| Day. | 1st. | 2d. | 3d. | 4th. | 5th. | 6th. | Total of Cases. |
| 100% fertilized | 5 | 4 | 4 | 5 | 5 | 5 | 28 |
| 20% fertilized | | | 1 | | | | 1 |
| None fertilized | | 1 | | | | | 1 |
| Total | | | | | | | 30 |

Average fertility = 94%.

the dishes were by chance interchanged, a certain amount of cross fertilization may of course have been possible.

On the three succeeding days (fourth, fifth, and sixth) greater precautions were taken, and the jars were dried as well as washed before the experiment was repeated. It will be observed that the proportion of eggs fertilized on those days was distinctly less than on the first three days.

Taking an average of the thirty cases in which eggs were laid in aquaria containing each *two* individuals (Table II.), we find that 94% of the eggs laid were fertilized.

The single instance in which none of the eggs laid in one aquarium were fertilized may be explained by a failure on the part of one of the two animals confined together to emit the sexual products on that particular occasion. Table I. indicates that such cases sometimes occur; for in two instances out of sixty no eggs at all were laid.

Comparing the results of the two tables, we see that under conditions allowing of only close (self-) fertilization (Table I.), less than 5% of the eggs developed; whereas under conditions permitting of cross fertilization (Table II.) at least 90% of the eggs developed.

The question now arose, Do eggs laid by isolated individuals fail to develop because the parent does not discharge sperm at the proper time (perhaps for want of stimulation by another individual), or do the eggs fail to develop because they are *incapable* of fertilization by sperm from the same parent? To settle this point if possible, resort was had to artificial fertilization.

### *Third Experiment.*

The same animals employed in the second experiment were also used in this one. Half of the individuals of each lot were taken for an attempt at close fertilization, the other half being reserved for an attempt at cross fertilization. Each animal was dipped in 90% alcohol to kill any spermatozoa which might be adhering to it; the fingers and instruments used were treated in the same way. Eggs and sperm were removed from the sexual ducts of the animal, and thoroughly mixed in a dish of clean fresh sea-water, the dish having been previously carefully washed and then dried.

The second ten were treated in exactly the same way, except that the sexual products — both male and female — of *two* individuals were mixed together in a single dish.

The proportion of fertilized eggs in each dish was subsequently carefully observed. The results are given in Tables III. and IV.

TABLE III. — Artificial Close Fertilization.

| | Cases. |
|---|---|
| 50 % fertilized | 1 |
| 4 % " | 2 |
| 1 % " | 1 |
| ⅓ % " | 2 |
| None " | 4 |
| Total | 10 |

Average for ten cases, 6% = proportion of eggs fertilized.

TABLE IV. — Artificial Cross Fertilization.

| | Cases. |
|---|---|
| 100 % fertilized | 4 |
| 50 % " | 1 |
| Total | 5 |

Average for five cases, 90% = proportion of eggs fertilized.

As the animals employed in the above experiment had been confined in the laboratory for some days, and the production of the sexual elements had in consequence considerably diminished, it was thought desirable to repeat the experiment on animals freshly collected. This accordingly was done with the following equally conclusive results.

TABLE III. *a.* — Artificial Close Fertilization.

| | Cases. |
|---|---|
| 50% fertilized | 1 |
| 12½% " | 2 |
| 10% " | 1 |
| 5% " | 1 |
| 2% " | 2 |
| None " | 3 |
| Total | 10 |

Average for ten cases, 9.4% = proportion of eggs fertilized.

TABLE IV. *a.* — Artificial Cross Fertilization.

100% fertilized in every case!

The proportion of close fertilized eggs was greater in this experiment than in the preceding. Many of the eggs so fertilized, however, never developed beyond the 2- or 4-cell stage. The cross fertilized eggs all developed normally and at the same rate.

Combining the results of Tables III. and III. *a*, and those of IV. and IV. *a*, we get an average of 7.7% of the eggs developing after close fertilization, and 95% developing after cross fertilization. These averages agree fairly well with those obtained from Experiment 2, which were 4.8% and 94% respectively.

Experiment 3 shows conclusively that, in the case of Ciona, eggs are to a large extent incapable of fertilization by sperm from the same individual as the eggs. Cross fertilization must, therefore, be the rule, and close fertilization the exception under natural conditions. The rare occurrence of close fertilization is probably due to a lack of mutual attraction between eggs and sperm produced by the same individual, an attraction invariably existing between the eggs of one individual and the sperm of another, and probably chemical in its nature. This case is paralleled in certain flowering plants, whose pollen will not germinate when placed on the stigma of the flower from which it was taken, though on the stigma of other flowers of the same species of plant it germinates readily.

There seems to be a particular time of day in the case of each species of simple Ascidian for the discharge of the sexual products. Different aquaria, in which are placed individuals of the same species, if they are subjected to the same conditions of temperature, etc., invariably contain eggs in exactly the same stage of development. This shows conclusively that the time of egg-laying has been the same in the case of each aquarium. For, on account of the rapidity of development, a slight difference in the time of egg-laying would be readily detected by a difference in the stage of development exhibited by the eggs in different aquaria. In the case of Ciona the sexual products are discharged about an hour or an hour and a half before sunrise. The stimulus to their discharge is probably the increasing light of daybreak.

If at about the time mentioned one approaches the aquarium with a lighted lamp, he will see the animals suddenly contract violently two or three times in succession, then resume their accustomed tranquillity. A careful examination will then reveal the eggs floating as little golden specks in the thoroughly agitated water. Soon they begin to settle to the bottom of the aquarium and can then be collected in convenient quantities by means of a pipette. The violent expulsion of the contents of the atrium simultaneously with the release of the sexual products from their respective ducts, must secure under natural conditions a wider distribution and more thorough mixing of the eggs and spermatozoa than would otherwise occur.[1]

The season of spawning of Ciona probably extends in this country, as in Europe, from spring to autumn. I have never collected adult specimens which did not contain mature eggs and spermatozoa, though I have taken them as early in the season as the 10th of June and as late as the 22d of September.

The development of the ovum is very rapid, as I shall show further on, and the larval period brief. The growth of the metamorphosed individual must also be very rapid, as the following facts indicate. In the summer of 1892 specimens of Ciona were abundant in a certain locality at Newport. But the succeeding winter was a cold one, and seems to have killed off those individuals which were situated in very shallow water. In the summer of 1893 specimens were to be found only at a depth of over two feet below low-water mark. In August and September of the next year, however, they occurred in abundance just below low-water mark. But those so situated were rather small, not exceeding 7 cm. in length, very clear, and free from dirt or parasitic growths, thus giving evident signs of youthfulness. They cannot have been over fifteen months old, and may have been much younger. Yet they were sexually mature, and produced eggs in abundance.

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[1] The time of egg-laying is about the same — viz. just before daybreak — in the case of Molgula Manhattensis, on which I made some observations in the United States Fish Commission Laboratory at Wood's Holl, Mass., in June and July, 1894. Cynthia, whose habits I studied at the same place, lays its eggs with equal clock-like regularity, but toward nightfall instead of at daybreak. The late afternoon is also the time of spawning for Amphioxus (Wilson '93, Willey '94). The *manner* of egg-laying is the same in Molgula as in Ciona. Herein my observations differ from those of Kingsley ('83), who states that in Molgula fertilization occurs within the atrium, and that the eggs are for some time afterward retained there. I have never found embryos within the atrial chamber, though I have often seen them adhering to the bodies of the parent individuals, where some eggs had probably settled at the time of spawning. My observations regarding the manner of cleavage in M. Manhattensis also differ from those of Professor Kingsley. He states that the cleavage is unequal, much as in certain Mollusks, and results in the formation of a cap of very small micromeres resting on a few very large macromeres. According to repeated observations of my own, made both on naturally and on artificially fertilized eggs, the cleavage progresses very much as in other Ascidians, the first two cleavages being equal. I think Professor Kingsley must have been misled by appearances in immature eggs obtained by dissecting out the ovaries for artificial fertilization.

Allusion has been made to the rapidity of development of the egg. Within twelve hours after fertilization the larval form is attained, the tail being coiled round the trunk within the egg membranes. Hatching usually occurs within the next twelve hours, i. e. in the first night after the laying of the eggs. It is brought about by twitchings of the larval tail, which finally rupture the egg membranes. Under certain conditions the larva does not succeed in breaking through the egg membranes. Metamorphosis then sets in almost immediately, and is completed within the egg membranes, a functionally free-swimming stage being wholly suppressed. This is regularly the case in Molgula Manhattensis, where hatching of the larva is exceptional, the new, metamorphosed individual arising just where the egg settled after it was thrown out into the water and fertilized. However, in Ciona the more primitive course of events is usually pursued. The larva then escapes from the egg membranes as a miniature tadpole, the "test cells" clinging to its thin and adherent covering of homogeneous, non-cellular mantle substance secreted by the ectoderm. These test cells are soon brushed off as the tadpole swims about; they have no connection, as is now well known, with the cells to be found later in the mantle of the adult.

The larvæ avoid the daylight and swim toward the least brightly illuminated side of the aquarium.[1] Here they attach themselves, usually near the surface of the water, to the side of the aquarium. Sometimes the attachment is by the head end, as it is commonly said to be, but I have more often observed the larvæ attached by the sticky mantle substance at the tip of the tail, the body then hanging head downward against the side of the aquarium.

The larval stage varies in duration from twenty-four hours to several days. It is terminated by the beginning of metamorphosis, whose successive steps are well known through the description of Kowalevsky ('66 and '92), Willey ('93), and others.

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[1] I have observed that the larvæ of Amarœcium also avoid the daylight, i. e. are negatively phototactic; but the larvæ of Botryllus are strongly *positively* phototactic, swarming *toward* ordinary daylight. This difference may perhaps be explained by the difference in habitat of the parent organisms. Botryllus, whose larvæ seek the light, is commonly found in well illuminated places, e. g. adhering to floating eel-grass. On the other hand, Ciona and Amarœcium, whose larvæ avoid the light, more often occur in darkened places, the former on the under side of stones, the latter adhering to piles underneath wharves, or on the sea bottom in sheltered spots near shore.

## III. METHODS.

### 1. Killing, Preservation.

Whenever it was desired to kill a lot of eggs, a sufficient quantity of them was collected in a pipette from the bottom of an aquarium and transferred to a watch-glass, or directly to a small vial of two drams' capacity, in which the eggs were ultimately stored. After the eggs had settled to the bottom of the dish, the water was carefully removed and the killing reagent applied.

The eggs were ultimately preserved in 90% alcohol, and the vials tightly corked, or preferably stoppered with cotton plugs and stored in tightly sealing glass jars. When the latter method is employed, the jars must be kept right side up in transportation, otherwise the small eggs will settle into the cotton plugs and be lost. However, the extra trouble which this method necessitates is well worth taking, for it entirely avoids the injurious effects on preserved material sometimes caused by the tannin which alcohol will extract from corks, if they are used.

Several killing reagents were employed, viz. Flemming's fluid, Hermann's fluid, picro-nitric, corrosive-acetic, and Perenyi's fluid.[1] The blackening effects of the first two reagents made material killed in them unfit for use in the study of eggs as whole objects. Likewise in the case of sections the results from them were disappointing. The only real service rendered by either of these two reagents was in demonstrating in the egg by their blackening effects the character and distribution of the fatty yolk granules. Most serviceable of all the reagents employed on the eggs and embryos up to the period of hatching was Perenyi's fluid. It renders the abundant yolk clear and transparent, and preserves all structures perfectly, without distortion by either swelling or shrinking. Its use does not in my experience interfere in the least with sharp differential staining. The fluid was allowed to act for about twenty minutes, then followed by 70% alcohol, which, to insure removal of every trace of the killing reagent, was changed once or twice in the course of the next twenty-four hours, and replaced at the end of that time with 90% alcohol. A longer treatment with the killing reagent, extending to three or four hours, seemed to give no added advantage, but to interfere slightly with subsequent staining.

Picro-nitric also gave good results, but for the pre-larval stages not so good as Perenyi's fluid, its clearing effects being less. It seems, however, to have been for the larval stages the best reagent which I employed. Davidoff's corrosive-acetic mixture, which has been much used of late by workers on ascidian embryology, is in my experience less faithful in its preservation than Perenyi's fluid, for it shows a tendency to swell certain structures, and lacks the instantaneous hardening effects of that reagent.

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[1] For the composition of the killing reagents and stains mentioned in this paper, see Lee's "The Microtomist's Vade Mecum," 3d edition, London, 1893.

### 2. Decortication, Staining, Mounting.

The egg of Ciona is surrounded by a series of egg membranes, a correct idea of which is given by the figure of the mature egg of Ascidia canina, reproduced after Kupffer ('72) in Korschelt u. Heider's "Lehrbuch d. vergl. Entwicklungsgeschichte," Figure 736. The egg cell is seen to be surrounded by a clear space — probably occupied by jelly — bounded by the test cells, which are arranged in a rather compact layer one cell deep, so that they seem almost to form an epithelium underneath the chorion. The chorion is a structureless transparent membrane, upon which, as on a basement membrane, the follicle cells ("Schaumzellen") rest. In the egg of Ciona, after it is thrown out into the water, these highly vacuolated cells are even more conspicuous than in the egg of Ascidia as figured by Kupffer. They extend out radially about twice as far as indicated by Kupffer's figure, forming a sort of halo round the egg. The highly refractive nuclei are carried out to the pointed outer ends of the tapering follicle cells.

The presence of the follicle cells and test cells did not interfere seriously with the study of the early stages of cleavage in the living egg, since the clear space between the egg cell and the layer of test cells allows one, with a sufficiently strong illumination, to make out perfectly the outline of the blastomeres and sometimes even nuclear figures in them. But upon preservation in alcohol the envelope formed by the test cells, chorion, and follicle cells collapses, obliterating the clear space and becoming closely applied against the egg cell, thus forming a very serious obstacle to the study of the egg as a whole object. This obstacle I was able to remove by following in a modified form a very ingenious method devised by Chabry ('87, p. 169) for the removal of the follicle cells from the living egg of Ascidiella, a process which he called "decortication." It consisted in simply sucking the eggs into a fine capillary glass tube too small to admit the eggs without the removal of their follicle cells, yet large enough to allow the passage uninjured of the egg itself.

In applying this method to preserved material, I first stained the eggs, as a rule, so that they might be more easily seen. Upon transferring them to alcohol of a low grade, or to water, the egg envelopes would again stand out clear of the ovum, as in the living egg. By then sucking the eggs one at a time into a glass tube of the proper calibre, the entire envelope, consisting of follicle cells, test cells, and chorion, could be removed with considerable facility, and in the majority of cases without injury to the egg itself. Eggs thus decorticated and then mounted afforded excellent surface views.

The eggs are rather opaque, on account of the large amount of yolk which they contain, so that any stain except a very faint one is an obstacle in the study of whole preparations. Excellent results were obtained by mounting in balsam, without any staining whatever, eggs which had been killed in Perenyi's fluid and decorticated.[1] But for the 64-cell and later stages staining was found desirable. Many carmine and hæmatoxylin stains were tried; the one which gave by far the best results being Orth's picro-carminate of lithium. The eggs were treated with a small amount of this stain in a watch-glass for from six to twenty-four hours, then washed thoroughly in water. By this method resting nuclei are stained bright rose-color, while all other structures take only a faint yellow color from the picric acid, and give up even this if the washing is sufficiently prolonged. But the carmine stain in the nuclei is extremely tenacious, and does not fade in the least upon prolonged washing in water or preservation for months in strong alcohol. After the eggs had been stained and decorticated, they were dehydrated, cleared in xylol or cedar oil, then mounted in balsam, the cover glass being supported with small glass rollers made from fine capillary tubes. These served the double purpose of preventing the crushing of the egg and allowing it to be rolled into any desired position by movement of the cover glass. Changing the position of the egg, however, is not often necessary, for at an early stage it takes on a flattened form, which causes it to come to rest with the dorsal or the ventral surface uppermost. This is the case at all periods between the 24-cell stage and that at which the neural tube begins to close, except for a brief period, when the embryo consists of from forty-six to sixty-four cells, and the vertical axis becomes equal to or even greater than the longitudinal axis. Then there is no single position of stable repose for the embryo, and rolling is often necessary to bring it into the positions desired.

The self-orientation of the egg during most of the early stages was of great service in sectioning. When this was desired, the egg, previously studied as a whole object, was returned to xylol. The transfer was accomplished by placing the slide on which it was mounted in a shallow porcelain dish containing a little xylol. This soon dissolved away the balsam, and left the egg free and clearly visible against the white background. The egg was next removed to a shallow watch-glass with a perfectly flat bottom, which was previously smeared with a thin layer of glycerine. Any superfluous xylol was removed from about the egg with filter paper, and a small amount of melted paraffine poured over it, enough to fill the watch-glass to a depth of 3 to 5 mm. The whole was then set over the paraffine bath for fifteen or twenty minutes, when it was placed floating on a dish of water to cool. This being accomplished, the paraffine block was removed from the watch-glass, and the egg, which of course had settled to the bottom and lay with its long axis parallel to the surface of the block, was oriented under the compound microscope in any manner desired. The thinness of the block generally allowed plenty of light to pass through it for this purpose, and it was usually not difficult, owing to the shape of the embryo, to determine its axes. Sections were usually cut $6\frac{2}{3}\,\mu$ in thickness.

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[1] I find that Lillie ('95) has obtained good results in the case of the eggs of the mollusk Unio by mounting, without staining, material killed in Perenyi's fluid. He, however, used glycerine instead of balsam as a mounting medium.

The staining which was found most advantageous for the study of the egg as a whole object was altogether too faint for sections. These were accordingly given a further staining after fixation to the slide. Ehrlich's hæmatoxylin was employed, diluted one half with water. After immersion in the stain for from twenty minutes to an hour, the sections were washed in water to remove the superfluous stain, then to decolorize were placed in 35% alcohol containing 0.1% hydrochloric acid. Here they were allowed to remain until quite pale in color, usually for about five minutes. They were then rinsed in 35% alcohol and held for an instant over the unstoppered mouth of an ammonia bottle, a treatment which gave the hæmatoxylin remaining in the sections a deep blue color, and insured the permanency of the stain. The sections were then passed through the grades of alcohol, cleared in xylol, and mounted in balsam. This process, when properly conducted, resulted in a beautiful and sharply differential double stain. The nuclei retained the light rose tint given them by the carminate of lithium, for the superadded hæmatoxylin stain had been entirely removed from them, except in the chromatic elements, which possessed a deep black color. Cell boundaries, attraction spheres, and other cytoplasmic structures, were clearly brought out, and the fundaments of various organs, as, for example, chorda, mesoderm, and definitive endoderm, were distinguished one from another with great sharpness

# PLATE I.

All Figures represent sections; magnification, 560 diameters. Yolk granules are not represented, except in Fig. 2.

Fig. 1. First maturation spindle, and formation of first polar globule.

Fig. 2. Portion of section through recently impregnated egg. The spermatozoön lies at the centre of a region free from yolk granules.

Fig. 3. Second maturation spindle.

Fig. 4. Section through the same egg in region of male pronucleus.

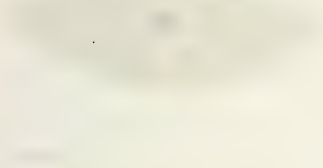
Fig. 5. Impregnated egg; male and female pronuclei visible in the same section.

Fig. 6. Conjugation of pronuclei, viewed in the direction of the axis of the first cleavage spindle, which is in process of formation. (Cf. Plate III. Fig. 13.)

1

4

2.



5

6

## PLATE II.

Figs. 7–10. Four sections through an impregnated egg; magnification, 560 diameters.

Fig. 7. Fourth section of series, showing the male pronucleus and archoplasmic spheres. Compare Figs. 11 and 12.

Fig. 8. Seventh section of series, showing the female pronucleus.

Fig. 9. Tenth section of series, showing the female archoplasm.

Fig. 10. Twelfth section of series, showing polar globules.

Fig. 11. Graphic reconstruction of the series on a plane, perpendicular to that of Fig. 7, indicated by the line *a b*, Fig. 7.

Fig. 12. A similar reconstruction on a perpendicular plane, the projection of which is the line *a′ b′*, Fig. 7.

12

10.

## PLATE III.

All Figures represent sections; magnification, 560 diameters.

Fig. 13. Conjugation of pronuclei, viewed in the direction of the equator of the first cleavage spindle. (Cf. Plate I. Fig. 6.)

Fig. 14. First cleavage spindle.

Fig 15. First cleavage nearly completed. Each of the newly formed nuclei is made up of two vesicles as yet incompletely fused.

Fig. 16. Section through one of the cells of a 2-cell stage, parallel to median plane of the embryo.

Fig. 17. Section from the same series as Fig. 16 through one of the two cells, near the median plane of the embryo. $x$, finely granular protoplasm, which marks the posterior-ventral side of embryo (cf. Plate VIII. Fig. 45, $x$), and is traceable up to the larval stage.

Fig. 18. Section through an 8-cell stage parallel to median plane of the embryo.

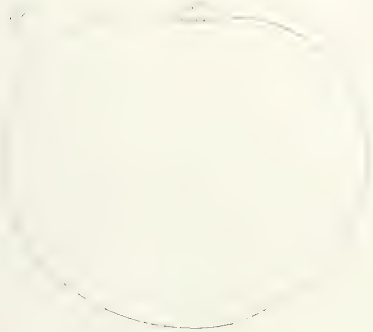
15
16
17

## PLATE IV.

Eight successive views of a living egg, seen from the left side; magnification, 315 diameters. Arrows indicate the direction of spindles.

| | |
|---|---|
| Fig. 19. | Matured but unsegmented egg. |
| Fig. 20. | 2-cell stage. |
| Fig. 21, | 4-cell stage approaching. |
| Fig. 22. | 4-cell stage, "resting" condition. |
| Fig. 23. | 8-cell stage, just formed. |
| Fig. 24. | 8-cell stage, nine minutes later. |
| Fig. 25. | 16-cell stage, just formed. |
| Fig. 26. | 16-cell stage, some minutes later. |

19.



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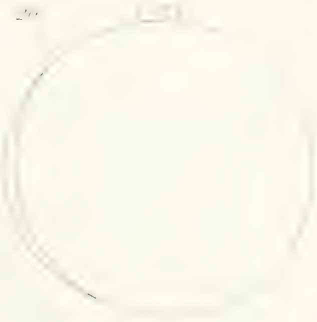

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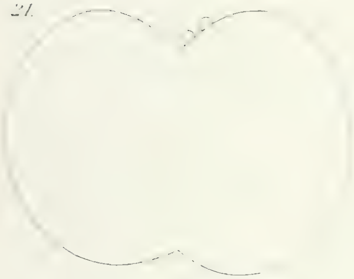
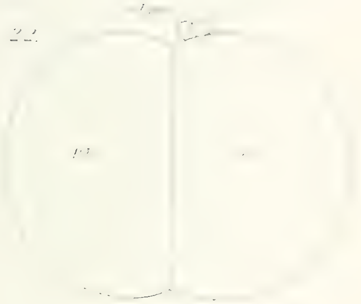
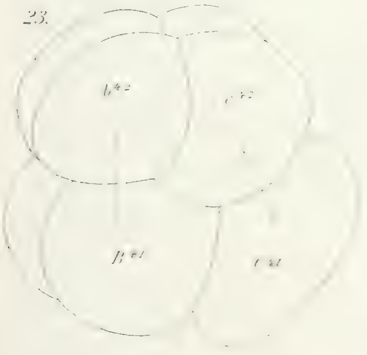


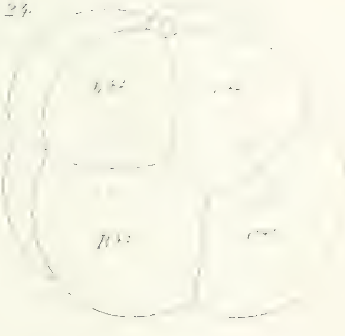
22.



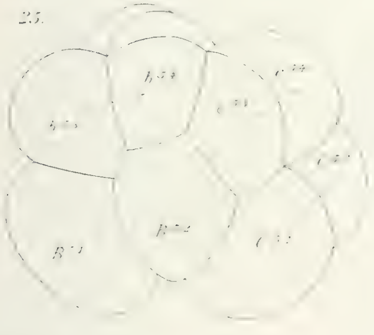
23.


$b^{4.2}$
$c^{4.2}$
$B^{4.1}$
$C^{4.1}$

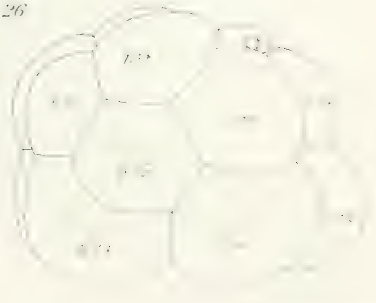
24.



25.



26.



W.E.C. del.

B. Meisel lith. Boston.

## PLATE V.

Six successive views of a living egg, seen from the anterior end; magnification, 315 diameters. Figs. 27–31 show the egg viewed as a transparent object. Fig. 32 is a surface view.

| | |
|---|---|
| Fig. 27. | 2-cell stage, newly formed. |
| Fig. 28. | 2-cell stage, a few minutes later. |
| Fig. 29. | 2-cell stage, a few minutes later still. |
| Fig. 30. | 4-cell stage. |
| Fig. 31. | 8-cell stage, just formed. |
| Fig. 32. | 8-cell stage, a few minutes later. |

## PLATE VI.

Magnification of all Figures, 315 diameters. Arrows indicate the direction of spindles.

Fig. 33. Later stage of the same egg as that shown in Fig. 32, Plate V. 16-cell stage, just formed.

Fig. 34. The same egg, passing into 24-cell stage.

Figs. 35–38. Ventral aspect of four successive stages of a living egg.

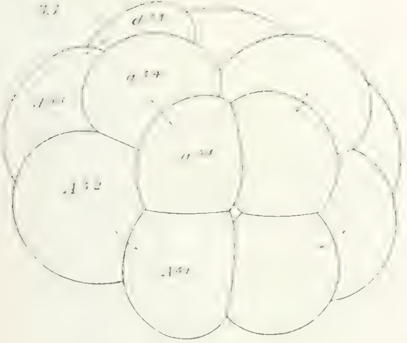
Fig. 35. 4-cell stage.

Fig. 36. 8-cell stage, just formed.

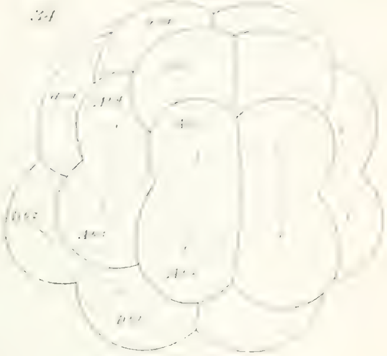
Fig. 37. 8-cell stage, a few minutes later.

Fig. 38. 12-cell stage, just formed.

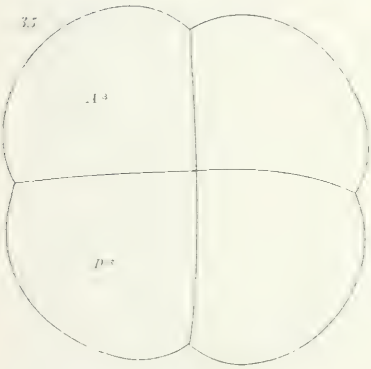
33


$d^{34}$
$a^{34}$
$A^{32}$
$a^{33}$
$A^{31}$

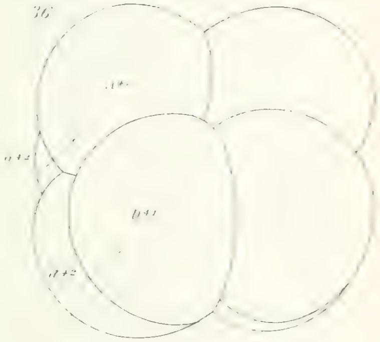
34


$A^{44}$
$A^{42}$
$A^{41}$
$p^{41}$

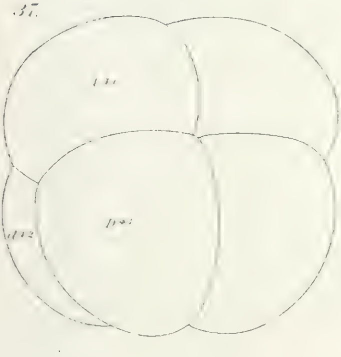
35



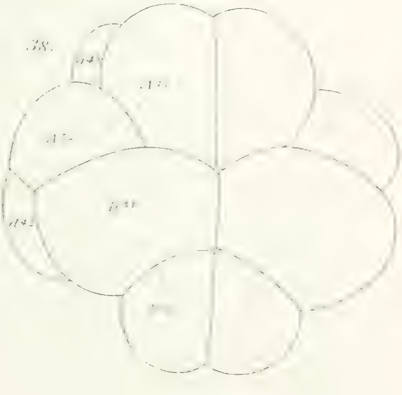
36


$A^{42}$
$a^{42}$
$p^{41}$
$d^{42}$

37.



38.


$a^{42}$
$A^{52}$
$p^{51}$
$d^{42}$

## PLATE VII.

Magnification of all Figures, except 43 and 44, 315 diameters; magnification of Figs. 43 and 44, about 300 diameters.

Figs. 39–42. Four later views of the egg shown in Figs. 35–38, Plate VI.; same (ventral) aspect.

Fig. 39. 16-cell stage, just formed. This view five minutes later than that in Fig. 38.

Fig. 40. 16-cell stage, five minutes later.

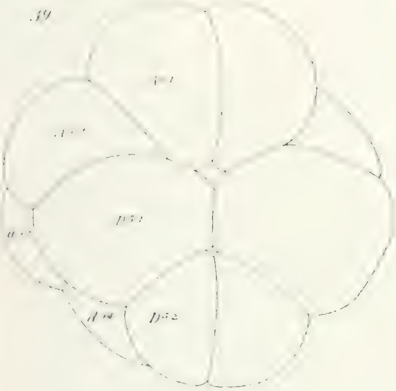
Fig. 41. 16-cell stage, ten minutes later still. Arrows indicate the direction of spindles.

Fig. 42. 24-cell stage, just formed, some minutes later than the last view.

Fig. 43. A late 24-cell stage, viewed from the right side.

Fig. 44. Optical section of the same egg, near the median plane. The cells of the dorsal hemisphere are in mitosis.

39.



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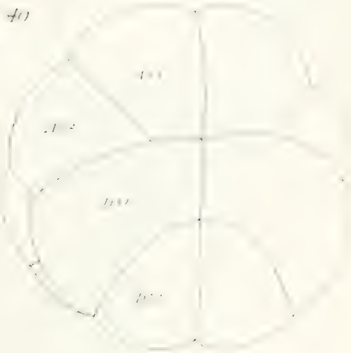
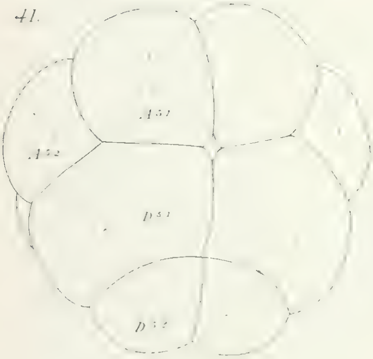
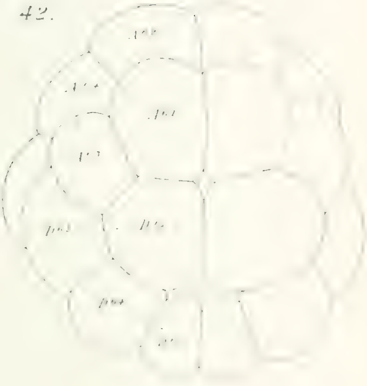


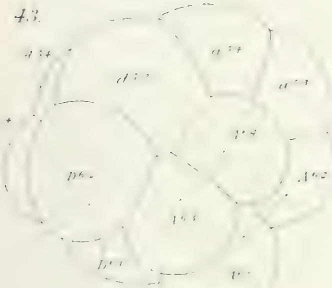
41.


A5.1
A5.2
B5.1
B5.2

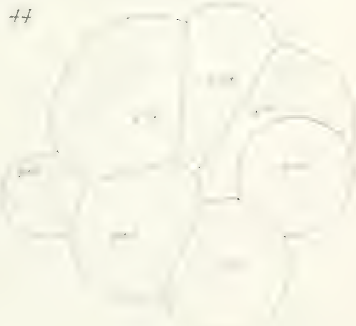
42.



43.



44.



## PLATE VIII.

Six successive views (obliquely from the left, above, and behind) of a living egg; magnification, 315 diameters. Arrows indicate the direction of spindles.

Fig. 45. 2-cell stage. $x$, region of finely granular protoplasm (cf. description of Plate III. Fig. 17).

Fig. 46. 4-cell stage, just formed.

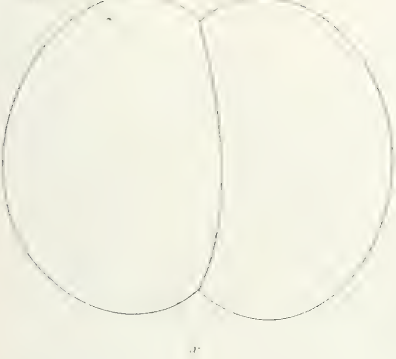
Fig. 47. 8-cell stage, approaching.

Fig. 48. 8-cell stage, fully formed (viewed as a transparent object).

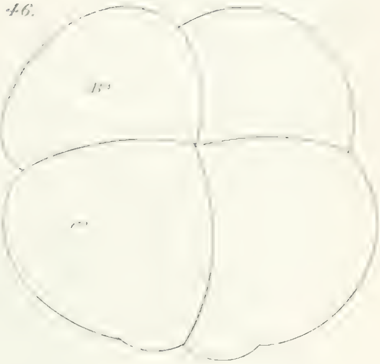
Fig. 49. 16-cell stage.

Fig. 50. 24-cell stage. During the formation of the 24-cell stage, the egg has rotated so that the view is almost exactly dorsal.

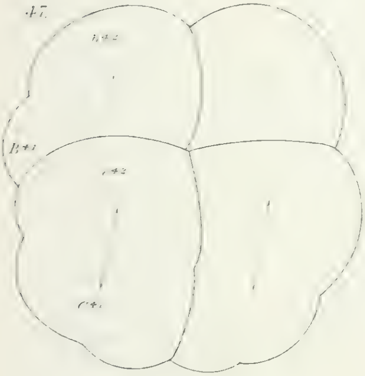
45.



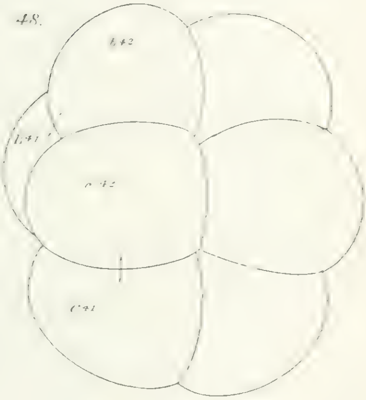
46.



47.



48.



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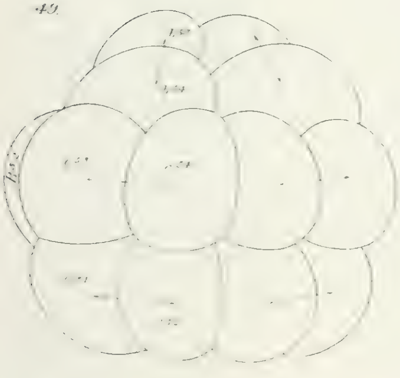

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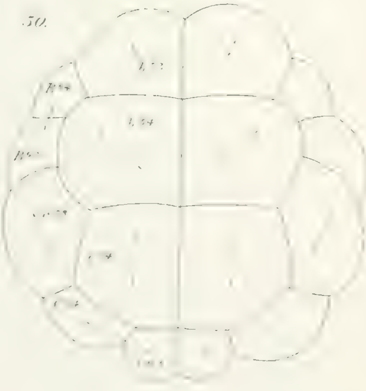


W.E.C. del.

## PLATE IX.

Surface views of preparations; magnification, 400 diameters.

Fig. 51. 24-cell stage, ventral view.

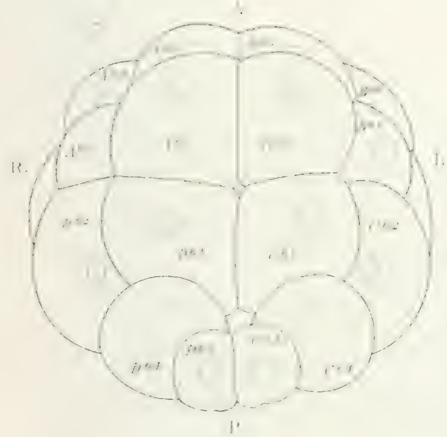
Fig. 52. The same egg, in the same stage, dorsal view (cf. Plate VII. Figs. 43 and 44).

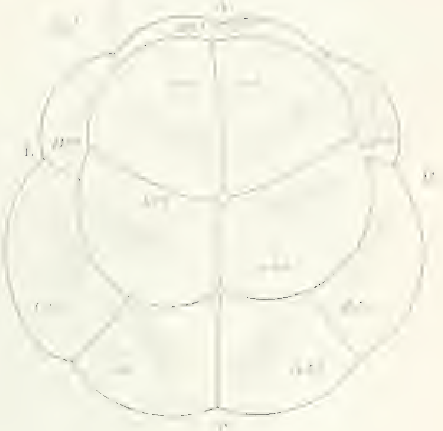
Fig. 53. 32-cell stage, ventral view.

Fig. 54. The same egg and stage, dorsal view.

Fig. 55. 46-cell stage, ventral view.

Fig. 56. The same egg and stage, dorsal view.


A
R.
L
P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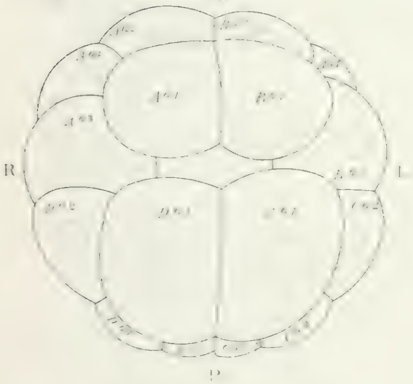
A.
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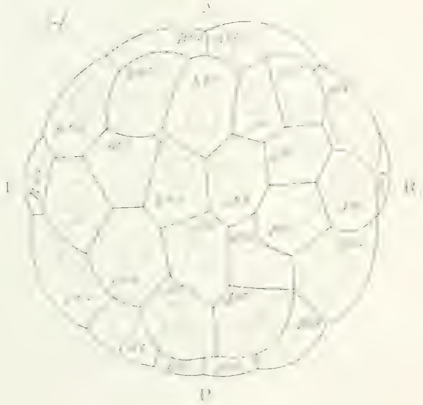
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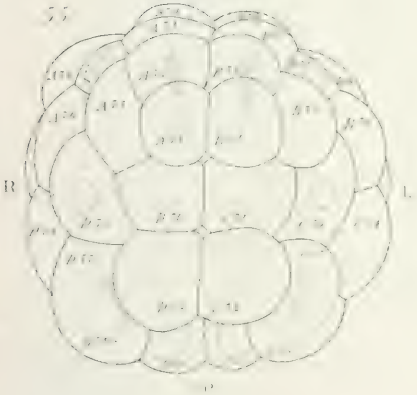
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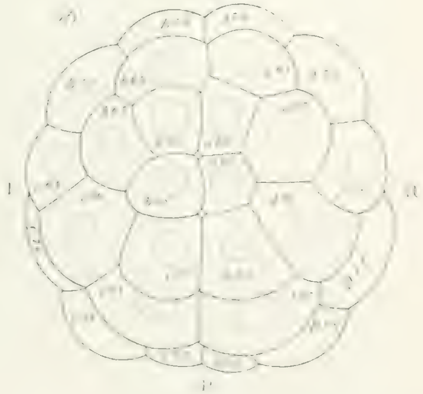

A
L
R
P

## PLATE X.

Figs. 57–62. Surface views of preparations; magnification, 560 diameters.

Fig. 57. 48-cell stage, viewed from behind.

Fig. 58. The same egg and stage, viewed from in front.

Fig. 59. 64-cell stage, ventral view.

Fig. 60. The same egg and stage, dorsal view.

Fig. 61. 76-cell stage, ventral view.

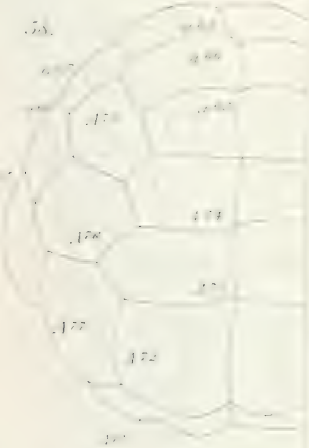
Fig. 62. The same egg and stage, dorsal view.

*Note.* — Consult general statement under Explanation of Plates. The cell $D^{8.6}$ and its mate in the left half of the Figure were stippled by mistake.

Figs. 63–70. Eight cross-sections from a series through an embryo in late 76-cell stage; magnification, 560 diameters. For position of sections in embryo, see horizontal lines 63–70 in Fig. 62.

*Note.* — In Fig. 63, the cells $D^{7.6}$ and $D^{8.14}$ should be stippled like their mates. In Fig. 67, the cell $C^{7.11}$ should be $c^{7.11}$.

58.



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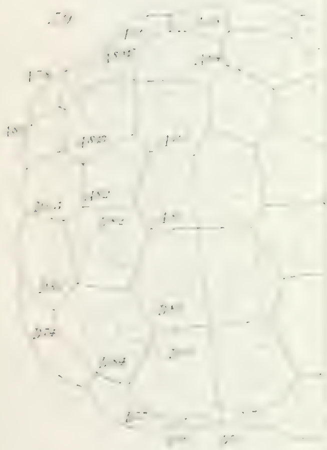

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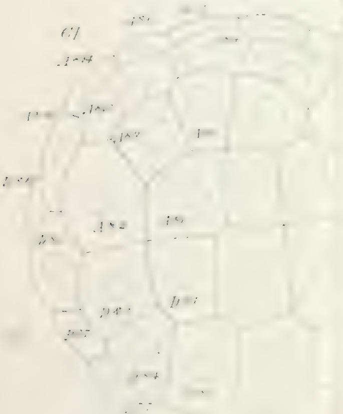

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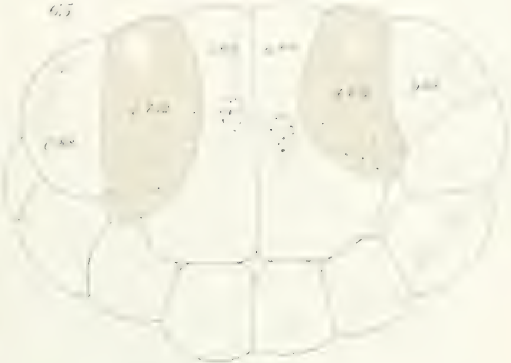

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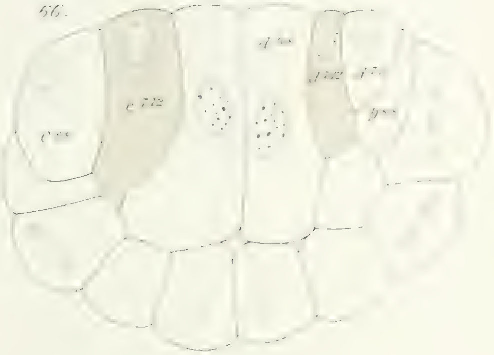

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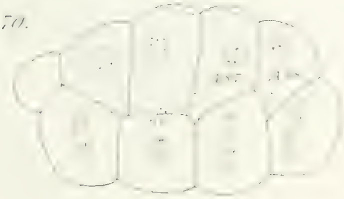

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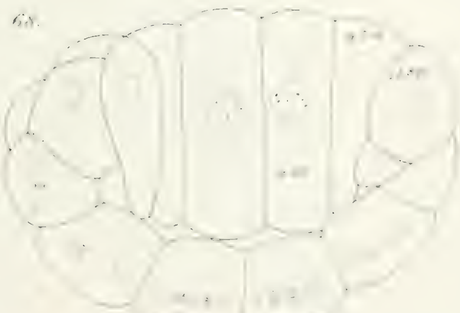
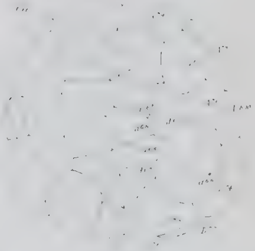


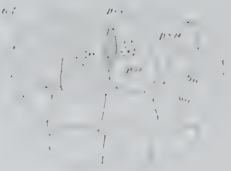
W.E.C. del.

B.Meisel, Bost.



62

63



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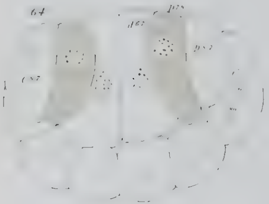

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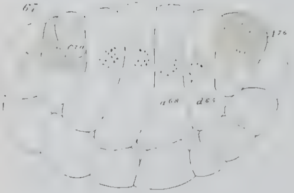

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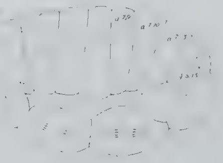

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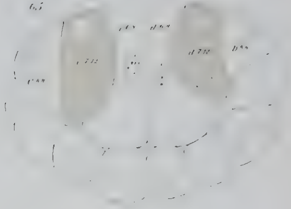

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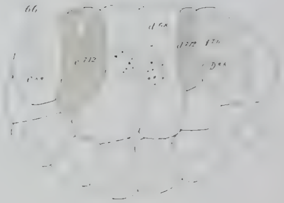

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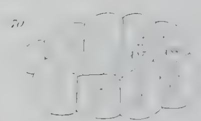

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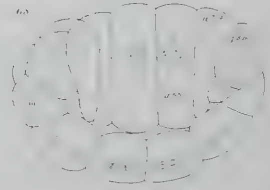


# PLATE XI.

Magnification of all Figures, 560 diameters.

Fig. 71. 112-cell stage, dorsal view.

Fig. 72. Early gastrula, dorsal view.

Figs. 73–77. Five cross sections through an early gastrula (128-cell stage). For position of sections in embryo, see horizontal lines 73–77 in Fig. 72.

*Note.* — Consult general statement regarding lettering under Explanation of Plates.

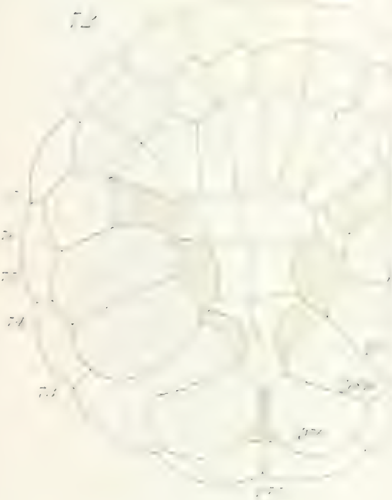
Fig. 78. Sagittal section through an early gastrula (older than that shown in Fig. 72).

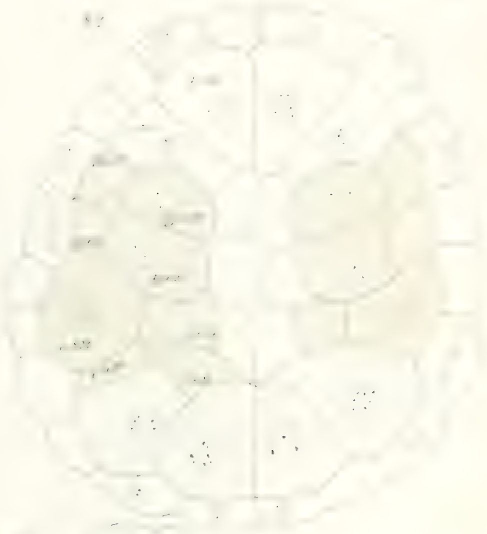
Fig. 79. Similar section through a slightly older stage.

Fig. 80. Surface (dorsal) view of late gastrula.

Figs. 81–83. Three horizontal sections from a series through a late gastrula.

72





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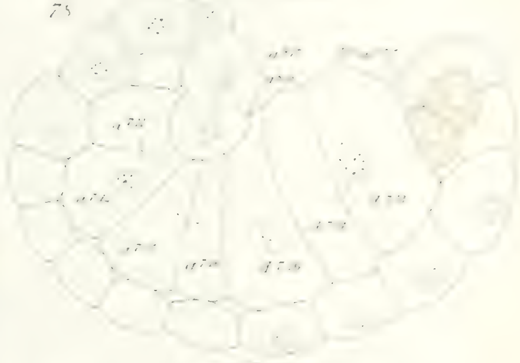

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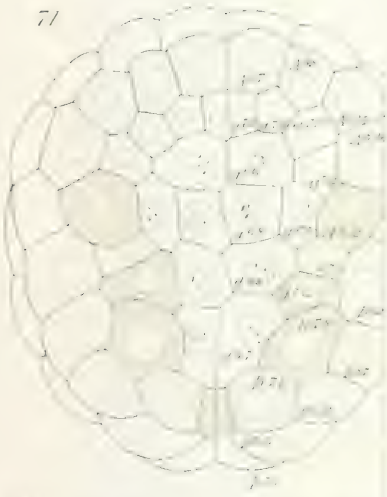

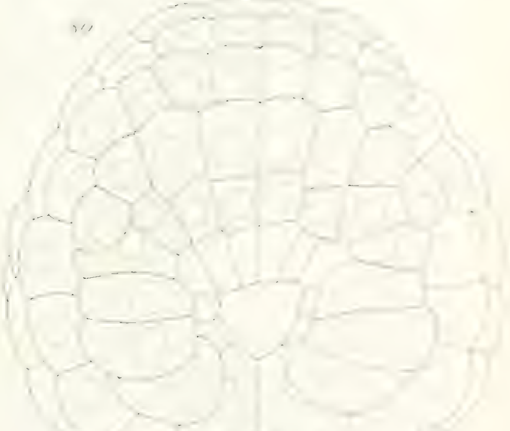

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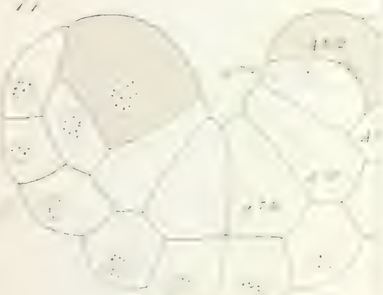

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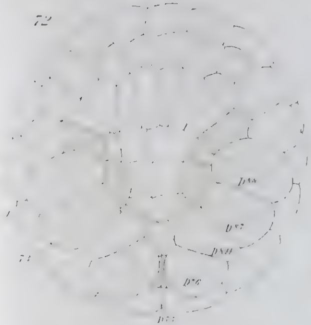
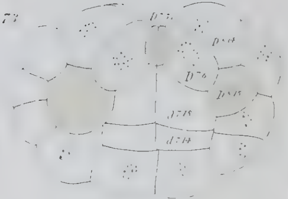


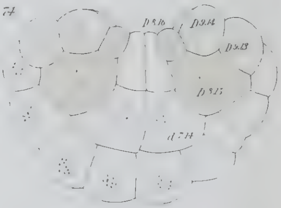
D8.8
D8.7
D8.11
D7.6
D7.5

73



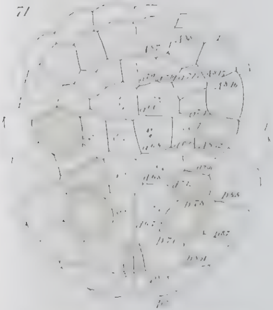
D7.5
D8.14
D7.6
D8.13
d7.15
d7.14

74



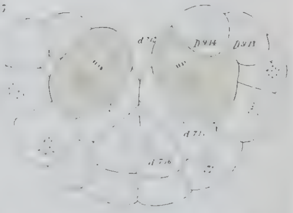
D8.16
D9.14
D9.13
D9.15
d7.14

71



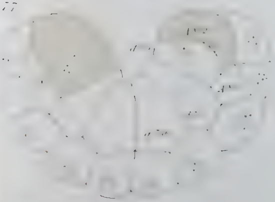
D8.16
D8.8
D8.7
D8.11

75



d7.2
D9.14
D9.13
d7.15
d7.16

77



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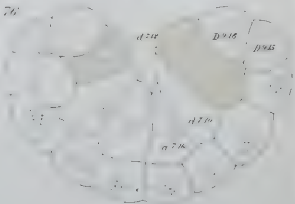
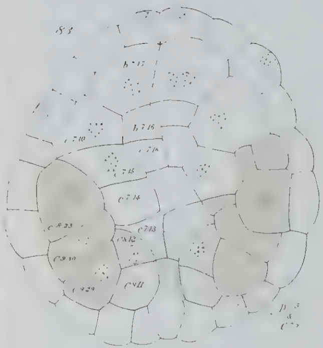


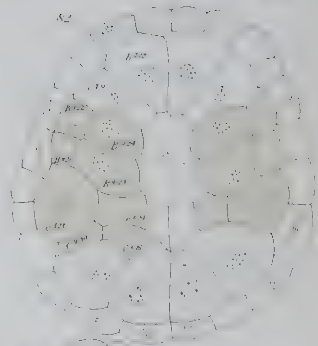
d7.12
D9.16
D9.15
d7.10
a7.16

83



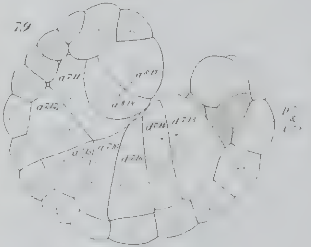
b7.15
b7.16
c7.10
c7.16
c7.15
c7.14
c8.23
c8.12
c7.13
c9.30
c9.29
c8.11
D & C

82



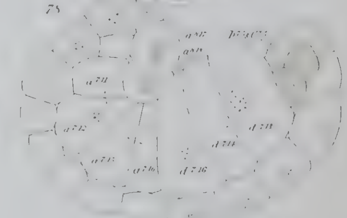
b7.12
B8.24
B8.23
c8.28
c9.30
c8.16

79



a7.11
a8.17
a7.12
a8.18
d7.16
d7.13
D & C

78



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a7.12
d7.11
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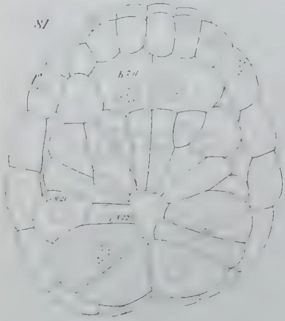
d7.16

81



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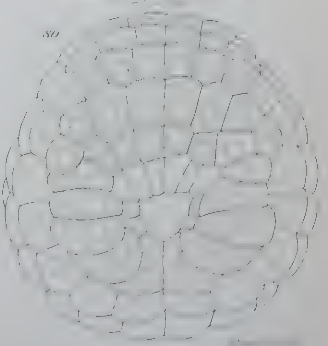


## PLATE XII.

Magnification of all Figures, 560 diameters.

Figs. 84–87. Four cross sections from a series through a gastrula with wide-open blastopore.

Fig. 84. Section posterior to the blastopore.

Fig. 85. Section through the posterior portion of the blastopore.

Fig. 86. Section through the anterior portion of the blastopore.

Fig. 87. Section anterior to the blastopore.

Figs. 88–92. Five cross-sections through an embryo with greatly contracted blastopore; Figs. 88 and 89 posterior to blastopore; Figs. 91 and 92 anterior to blastopore.

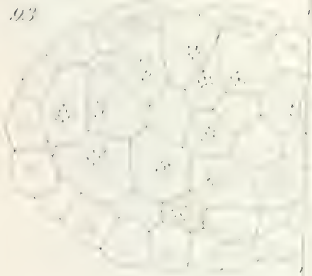
*Note.* — The large unstippled cell in the left half of Fig. 88 should have been stippled.

Figs. 93–97. Five cross sections through a slightly older embryo. Compare vertical lines 93–97 in Fig. 98. Fig. 93, section posterior to blastopore; Figs. 95–97, sections anterior to blastopore.

*Note.* — The large unstippled cell in the left half of Fig. 93 should have been stippled, likewise two large cells situated laterally in Fig. 95, one in either half of the Figure.

Fig. 98. Sagittal section through an embryo with nearly closed blastopore.

93



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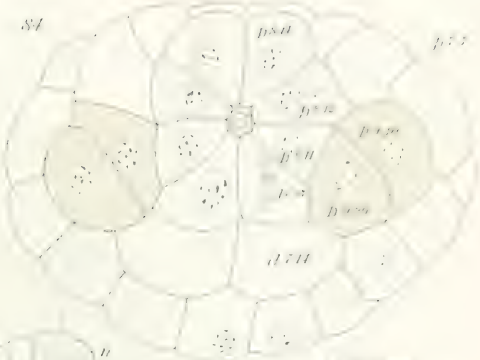
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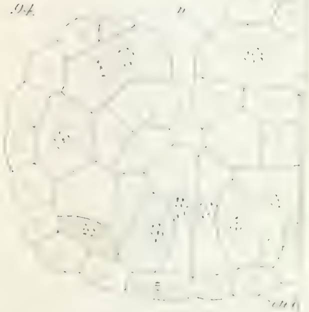
p 5 5
p 8 b
p 8 a
p 5 b
d 7 a

94



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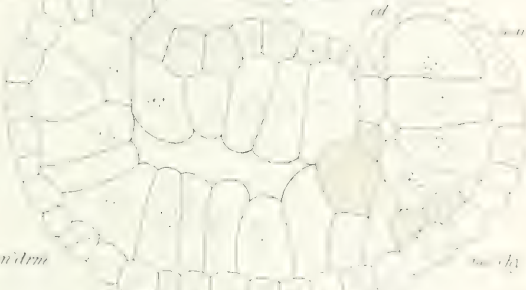
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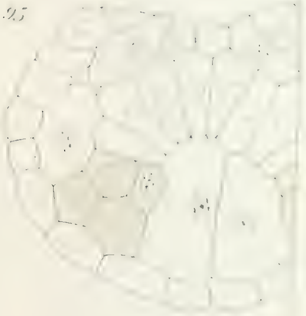
93

95



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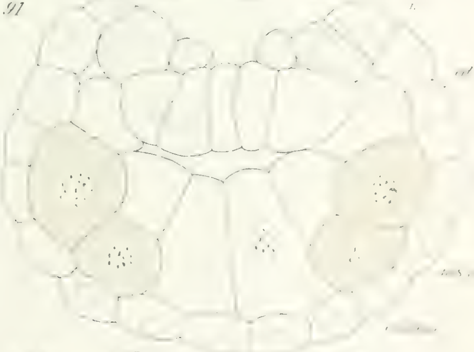

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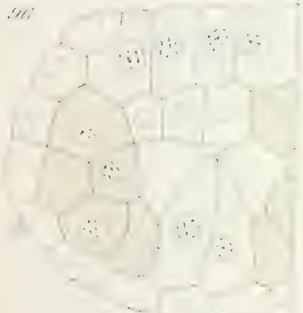

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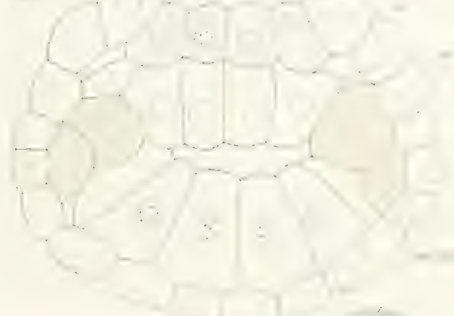

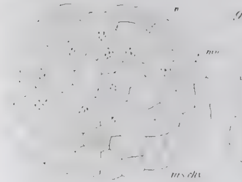

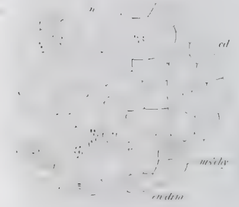
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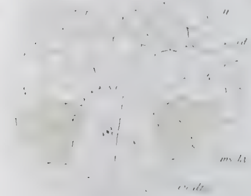
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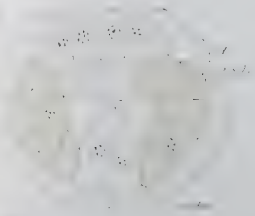

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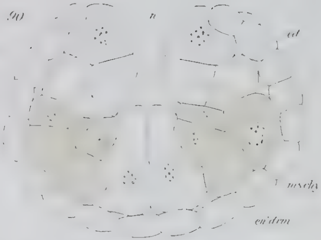
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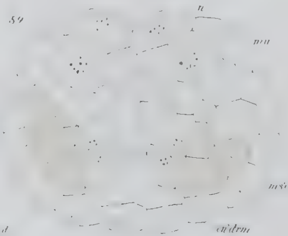
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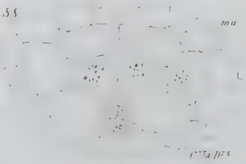

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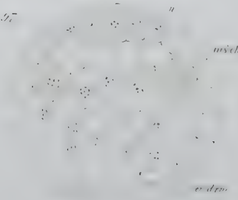
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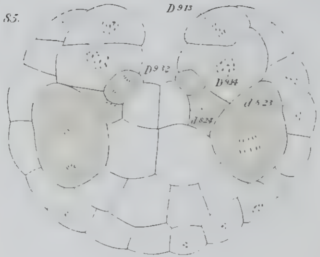
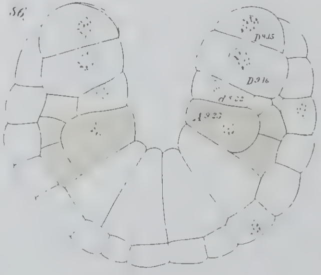
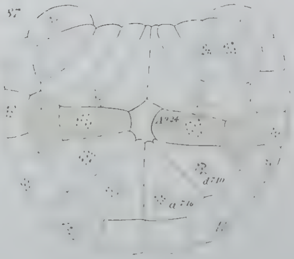

D 9.13
D 9.32
D 9.14
d 5.23
d 8.24

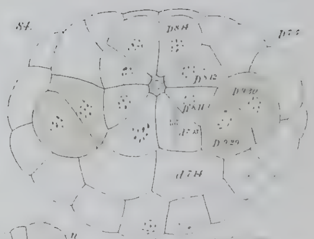
86.


D 9.15
D 9.16
d 8.22
A 9.23

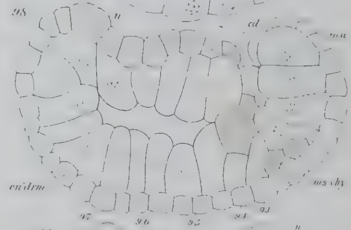
87.


A 9.24
d 7.10
a 7.16

84.


D 8.11
p 7.7
D 8.12
D 9.30
D 8.11
d 7.13
D 9.29
d 7.14

98.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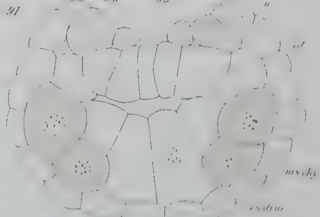
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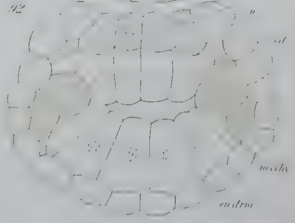
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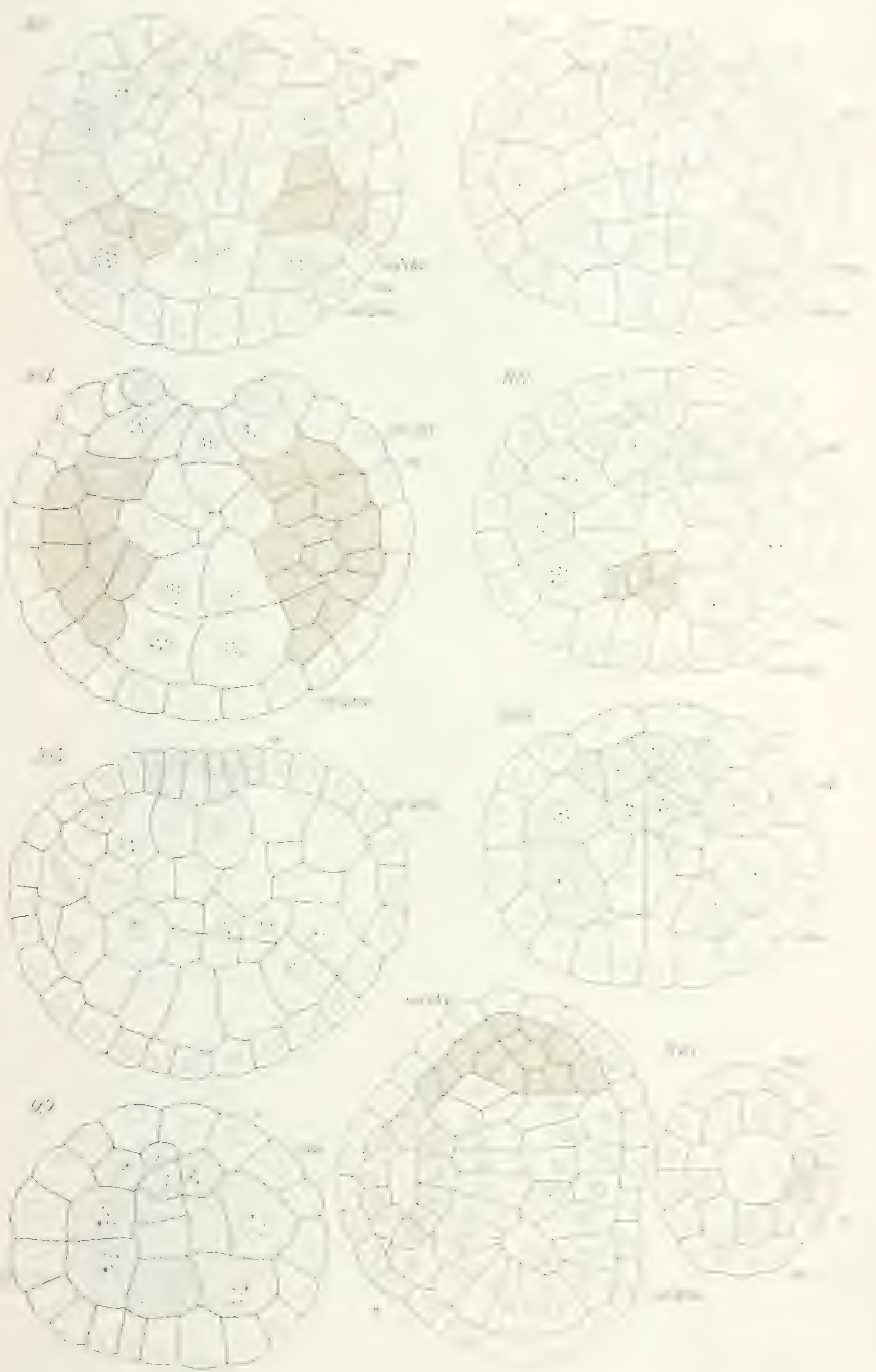
## PLATE XIII.

Magnification of all Figures, 560 diameters.

Figs. 99–105. Seven sections from a series through an embryo with completely closed blastopore. Figs. 99–101, posterior to region of final closure of blastopore; Figs. 103–105, anterior to region of closure of blastopore.

Fig. 106. Cross section through an early larval stage (unhatched). The trunk region is shown in the left portion of the Figure, the tail region in the right portion.



by the different tints of blue which they exhibited. Iron hæmatoxylin was sometimes employed instead of Ehrlich's, but the results were no better — indeed not so good — for the differentiation of organs or their fundaments.

For studying the processes of maturation and fertilization sections alone could be employed on account of the opacity of the eggs. In making sections of these stages orientation was of course impossible, so that a large number of the eggs was embedded together, without previous decortication, and cut at random. The egg membranes, so far from being an obstacle, were at these stages a positive advantage, since they served to protect and hold the polar globules in place. The material employed in the study of maturation and fertilization stages was killed either in Perenyi's or in Hermann's fluid, the best results being obtained from the former. For convenience the killing of each day will be referred to as a series (A, B, or C), made up of lots (1, 2, 3, etc.) which were killed at intervals of about ten minutes, the first lot being killed as soon after the laying as a sufficient number of eggs could be collected, usually about five or ten minutes.

## IV. MATURATION AND FERTILIZATION.

The eggs of series A, lot 1, show an early stage in the process of maturation, namely, the formation of the first polar globule. Figure 1 represents a section through one of the eggs of this lot most advanced in development. The egg envelopes, which rest close down upon the egg, are left out in this and all the other figures. Already at this stage we recognize that the egg is made up of two unlike hemispheres, one richer in yolk, the other richer in protoplasm. The former occupies the future *dorsal* or *endodermal* side of the egg, and at the centre of its surface, as stated in my preliminary communication ('94), the polar globules form. The cell division which will give rise to the first polar globule is seen in this figure to be already well advanced, the chromatin being accumulated at the two ends of the spindle. About the deeper end of the spindle there is a small space free from yolk granules and occupied by a finely granular deeply staining mass of protoplasm, of which we shall have more to say. The entire remainder of the dorsal hemisphere, except that small portion of it occupied by the spindle itself, is filled with rounded yolk granules (cf. Fig. 2) of a rather uniform size, closely packed together, but with slender films of staining protoplasm passing between and around them. Davidoff's ('89) beautiful figures, particularly his Tafel VI. Fig. 33, give a correct idea of this "Schaumwerk" structure, if one imagines the yolk granules many times smaller and the protoplasmic films much more slender than in the egg of Distaplia as represented by Davidoff.

The ventral hemisphere also is filled with yolk granules, but here the protoplasmic packing between them is more abundant and less uniformly distributed. It is most conspicuous at the surface, where it forms a thin layer nearly free from yolk granules spreading over almost the whole hemisphere. Within this layer it fades away gradually, but often, as in the case figured (Fig. 1), again becomes prominent at a little deeper level as a series of irregular blotches among the yolk granules; then it once more grows fainter toward the centre of the egg, attaining the condition described for the dorsal hemisphere.

The presence of a spermatozoön cannot be detected in the eggs of this lot. In those of Series B, lot 3, however, its influence is clearly visible. (See Figs. 2 and 4.) About fifteen minutes is estimated to have elapsed between the stage just discussed and the one here presented. At this stage we see in the ventral hemisphere, at some point just beneath the surface, a spherical region entirely free from yolk granules. (See Fig. 2.) Its central portion is occupied by a finely granular substance, which stains in hæmatoxylin an intense blue, shading off somewhat gradually into the more faintly and lightly colored protoplasm occupying the outer portion of the area and continuous with the similarly stained films of the Schaumwerk. At one point the yolk-free region extends out to the surface of the egg. This probably represents the place of entrance of the spermatozoön, which we have reason to believe produces the clear area. The deeply staining substance at the centre of this area is the *male archoplasm* or attraction sphere. It is undoubtedly similar in nature, as it is in optical appearance, to the darkly stained substance seen at the deep end of the maturation spindle in Figure 1, and which may therefore be called the *female archoplasm.* The male pronucleus cannot be made out in the egg a portion of which is shown in Figure 2. In other eggs of the same lot, however, it can be clearly seen; for example, in Figure 4, which represents a stage a little more advanced than the one seen in Figure 2. The area free from yolk is seen in Figure 4 to have enlarged somewhat; the attractive influence of the archoplasm at its centre has manifestly been extended over the greater portion of the hemisphere in which it lies. This fact is indicated *diagrammatically* by the dotted lines in the figure. They are meant simply to indicate that those films of the protoplasmic Schaumwerk which run radially with reference to the attraction sphere have become thicker and more prominent than those running in other directions. Along them as radii doubtless protoplasm is passing to augment the yolk-free area. Nothing in the nature of "fibres" has been observed in them. Excentrically situated in the yolk-free area (Fig. 4) is seen the male pronucleus, a perfectly clear oval body, with a delicate but sharp boundary. Its long axis lies radially with reference to the attraction sphere, which manifestly exerts on it a directive influence. Figure 4 represents the eleventh of a series of eighteen sections. The sixteenth section of the series is shown in Figure 3. It contains the second maturation spindle, at either end of which is an attraction sphere in the centre of a slight accumulation of protoplasm. The chromosomes cannot be clearly made out, but perhaps lie aggregated in a small dark mass close down against the attraction spheres. It is evident that the amount of chromatin involved in this division is less than in the case of the first maturation division (cf. Fig. 1). The obliquity of the plane of sectioning to the dorso-ventral axis of the egg makes this spindle appear to lie quite a little below the surface of the egg. Such, however, is not the case; it comes close up to the surface, but obliquely, not vertically, as did the first maturation spindle. Indeed, an examination of other specimens, less advanced, shows that it first appears in a horizontal position, i. e. at right angles to the direction of the first maturation spindle as seen in Figure 1, but later rotates so that one end of the spindle lies deeper in the egg than the other.[1] The first polar globule does not really lie in this section, but has been projected there from its real position on the margin of the next section, the seventeenth of the series.

In Figure 5 is represented a section, the fifth of a series of sixteen, through an egg of Series A, lot 3, killed twenty minutes later than lot 1 of the same series (cf. Fig. 1). The section passes obliquely in a dorso-ventral direction, unlike those shown in Figures 2–4, which were more nearly horizontal. On the ventral margin of the section is seen the cap of protoplasm which as early at least as the beginning of maturation covered that side of the egg. The male archoplasm has moved deeper into the egg, and its attractive influence has been extended so that it is now manifested over the greater portion of the section. In consequence of this attraction on the protoplasm the area free from yolk has considerably enlarged. The male pronucleus has also increased in size and followed the lead of its attraction sphere toward the centre of the egg. In the dorsal half of the section is seen the female pronucleus, already grown to considerable size. In it can be discerned small chromatic granules, and behind it and deeper in the section the female archoplasm. This archoplasm seems to be much less energetic than that of the male element, for its influence is scarcely perceptible, even on the portion of the egg in which it lies, and it does not appear to modify either the shape or course of the female pronucleus, which, as we shall see, moves toward the male archoplasm leaving its own behind. The polar globules represented at the margin of this section do not as a matter of fact occur in that position, but at the margin of the preceding section. If that section were properly superposed on this, the polar globules would lie over, but a little to the left of the female pronucleus.

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[1] A rotation of the maturation spindles from an original tangential to a radial position has been observed repeatedly in other animals; in the case of the second spindle, the tangential position is doubtless correlated with the derivation of its two archoplasmic masses from the single archoplasmic mass left in the egg after the completion of the first maturation division.

A stage somewhat later than the one just described, though found in the same lot of eggs, is shown in Plate II. Figures 7–10, which represent the fourth, seventh, tenth, and twelfth sections respectively of a series of sixteen. In Figure 7 is seen the male pronucleus with its archoplasm now divided; in Figure 8, the female pronucleus; in Figure 9, the female archoplasm; and in Figure 10, the polar globules marking both the centre of the future dorsal surface of the embryo, and the point from which the female pronucleus starts in its journey through the egg toward the male pronucleus. The position of these various bodies with relation to one another can be most clearly illustrated by two reconstructions (Figs. 11 and 12) upon planes perpendicular to the plane of sectioning and at right angles to each other. Suppose the sections piled one above another in their original order and position, the first section of the series being uppermost and the egg thus reconstructed to be viewed as a transparent object in the direction of the arrow at the left of Figure 7. One would then see the appearance shown in Figure 11, which is a projection of the egg and the most important bodies in it upon a plane parallel to the line *a b* (Fig. 7), and perpendicular to the plane of Figure 7.

If the egg be viewed in the direction of the arrow at the top of Figure 7, one gets the appearance shown in Figure 12, which is a projection upon a plane parallel with the line *a′ b′* in Figure 7, and perpendicular to the plane of that figure.

A comparison of the stage under discussion with that represented in Figure 5 shows that considerable changes have occurred in the interval between them. The male pronucleus (Fig. 7) has grown to much greater size and contains several conspicuous chromatic granules. Instead of a single attraction sphere, there are two, both well defined and at a considerable distance apart. An examination of other eggs of the same lot shows how the condition here existing has come about. The male archoplasm moving in advance of its pronucleus (cf. Fig. 5) has gradually elongated transversely to its line of progress, arranged itself about two centres instead of one, and finally constricted itself into two distinct spherical masses, which move apart, and by their combined action on the male pronucleus draw it forward to a position midway between them, so that its long axis lies in the line joining their centres. The female pronucleus (Fig. 8) has approached to within a short distance (about one fifth the diameter of the egg) of the male pronucleus.

It has grown to an equal size with the male pronucleus, and, like it, contains large chromatic granules. No trace of an archoplasmic body can be seen in connection with it, nor in either of the adjacent sections. However, what are unmistakably the remains of one are visible three sections behind the female pronucleus. (See Fig. 9; compare also Figs. 11 and 12.) This archoplasmic body shows signs of disintegration, being rather diffuse and exerting apparently no attractive influence on the egg protoplasm. The female pronucleus has clearly passed beyond its control, and is now advancing rapidly to unite with the male pronucleus. One might doubt that the body described is identical with a female archoplasm, were it not perfectly constant in its appearance at this stage *behind the female pronucleus in the path of the latter from the point where the polar globules were formed toward the male pronucleus.* Moreover, though diligent search has been made, a similar body has never been found at this stage in any other portion of the ovum, except in connection with the male pronucleus.

In from five to ten minutes after the stage just described the two pronuclei are seen to have come together (Plate III. Fig. 13, and Plate I. Fig. 6). They are indistinguishable from each other so far as size and optical appearance are concerned, and are flattened against each other, but their nuclear membranes remain intact, and there is no mingling of their substance until the first cleavage is about to take place. (See Plate III. Fig. 14.) At the stage shown in Plate II. Fig. 7, we saw that the male pronucleus was already elongated between its two attraction spheres. The female pronucleus is seen in Figure 13 (Plate III.) to have joined it while it is still in that condition. Both have further increased in size. Very soon the nuclear membranes disappear, the attraction spheres move farther apart (cf. Figs. 13 and 14, Plate III.), and a spindle forms between them, on whose equator are seen the chromosomes.

To recapitulate. *In the impregnated egg of Ciona two archoplasmic masses can be recognized, one in connection with each of the pronuclei. That derived from the spermatazoön is much the more energetic of the two, and is alone concerned in bringing the pronuclei together. While the pronuclei are still a considerable distance apart, the male archoplasm divides into two distinct attraction spheres, between which the first cleavage spindle later forms. The female archoplasm degenerates, taking no part whatever in the formation of the first cleavage spindle. There is accordingly in the fertilization of Ciona no union of male and female archoplasms.*

Let us compare briefly these conclusions with those of other recent observers on the subject of the attraction sphere in fertilization.

The fertilization of the Tunicate egg has been studied hitherto by Boveri ('90) and Julin ('93). Boveri's observations, made on Ciona intestinalis and Ascidia mentula, were, as he states, incomplete on account of an accident to his preserved material. It was his opinion that no astral radiations ("Polstrahlungen") are present in the maturation of the egg, and that the two asters of the first cleavage spindle are derived by division from a single one arising in connection with the spermatazoön soon after its entrance into the egg. Julin was able to confirm on Styelopsis grossularia the observations of Boveri, and to supplement them, as he says, by demonstrating at the centre of each aster of the first cleavage spindle a centrosome. No figures, however, accompany Julin's paper; moreover, he states that his observations were restricted to two stages, corresponding to those shown in Boveri's Tafel XII. Figs. 27 and 29.

Though my own conclusions are in entire agreement with those of Boveri and Julin as to the derivation of the attraction spheres of the first cleavage spindle exclusively from the spermatazoön, my observations differ from theirs regarding certain minor points, as the reader may learn by consulting the papers cited.

On the subject of fertilization in groups of animals other than the Tunicata there is an enormous literature. I shall refer to only a few of the most recent papers.

In 1891 Fol described the famous "quadrille of the centres" as occurring in the fertilization of the sea-urchin egg. According to his account, there arises in the egg from the tip of the spermatazoön, a centre of attraction ("spermocentre"), which later divides. In connection with the egg nucleus appears another centre of attraction ("ovocentre"), which likewise divides. Upon the meeting of the pronuclei, each half-spermocentre unites with a half-ovocentre to form an astrocentre. The two astrocentres arise on opposite sides of the cleavage nucleus, and between them the first cleavage spindle forms.

A short time after the publication of Fol's paper, Guignard ('91) described as occurring in the fertilization of a flowering plant a similar union of male and female centres of attraction ("sphères directrices"). More recently Conklin ('94) has observed its occurrence in the case of a mollusk, Crepidula.

Fol's observations, however, are flatly contradicted by the careful studies of Wilson and Mathews ('95) on three different genera of Echinoderms. They find that "the central archoplasm sphere ('attraction sphere') of the cleavage amphiaster is derived by direct and unbroken descent from the central mass of the sperm-aster without visible participation of an egg-aster."

Fick ('93) also observed that in the fertilization of a Vertebrate, Axolotyl, the centrosomes of the first cleavage spindle are derived exclusively from the spermatozoön. Brauer ('92) arrived at a similar conclusion regarding the fertilization of a crustacean, Branchipus, and Mead ('95) regarding a worm, Chætopteris. These observations are in entire agreement with those made prior to Fol's announcement of the "Quadrille" by Boveri ('88) on Ascaris and Sagitta, and by Vejdovsky ('88) on Rhynchelmis. Boehm ('88) had also expressed with some caution a similar view regarding Petromyzon.

On the other hand, Wheeler ('95), in a paper published simultaneously both with that of Wilson and Mathews and with that of Mead, states that in Myzostoma both centres of attraction arise in connection with the *egg nucleus*, none whatever being produced by the spermatozoön.

### Summary on Maturation and Fertilization.

(1) *In a majority of the animals in which fertilization has been most recently studied the attraction centres of the first cleavage spindle are derived from the spermatozoön and from the spermatozoön only.*

(2) But *in the fertilization of at least one animal, and undoubtedly in all cases of parthenogenetic development, the attraction centres arise solely in connection with the egg nucleus.*

(3) *Both these facts prove conclusively that the archoplasm, or "organ of division," is not a bearer of heredity,* since in fertilization it may be derived from the sexual product of one parent only, whereas it is a well recognized law that heritable substance is contributed to the offspring by *both* parents equally.

(4) If the archoplasm is furnished in some cases by the sperm only

and in others by the ovum only, it is not inconceivable that in yet other cases *both* may contribute to its formation. Therefore the observations of Guignard and Conklin are not necessarily irreconcilable with those more recently made by Wilson and Mathews, Mead, Wheeler, and myself, as well as the earlier observations of others. In any case, however, the theoretical conclusions based on Fol's "quadrille," as to the share which the attraction centres enjoy in the phenomena of heredity, may now be definitely set aside.[1]

## V. POLARITY OF THE EGG.

Attention has already been called to the fact that even before fertilization one axis of the egg, the vertical, has been determined. The point where the polar globules form is its dorsal pole, which lies at the centre of the surface of the *less richly protoplasmic* hemisphere. At some point on the surface of the opposite hemisphere, the spermatazoön usually enters the egg, and there is reason to believe that its point of entrance determines the median plane of the embryo, and so its antero-posterior axis.

After the two pronuclei have met, they move toward the centre of the egg, and in that region the first cleavage spindle arises (Plate III. Fig. 14). It invariably lies parallel to a tangent at the point of formation of the polar globules. The first cleavage plane, which in accordance with a general law is perpendicular to the spindle at its equator, passes through the point where the polar globules arose and divides the egg into two equal blastomeres (Plate III. Fig. 15; cf. Plate V. Fig. 27).

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[1] Boveri ('95), in a paper recently received, completely confirms the observations of Wilson and Mathews regarding the source of the attractive bodies of the first cleavage spindle of the sea-urchin egg. He for the first time in his published writings, so far as I know, gives a formal definition of the centrosome, applying the term to what Wilson and Mathews call the "archoplasm." Boveri, if I rightly understand him, recognizes an archoplasm surrounding the centrosome, at least at certain stages, and specifically different both from the centrosome and from the general cytoplasm.

What in the foregoing pages I have called indifferently *archoplasm* and *attraction sphere* undoubtedly corresponds with what Boveri in his latest paper ('95) defines as the centrosome. A centrosome in the sense of Heidenhain, that is, a simple, distinct granule staining black in iron-hæmatoxylin, I have not been able to detect in the egg of Ciona; nor have I observed a substance (Boveri's archoplasm) specifically distinct from the egg cytoplasm, enveloping the attractive body (Boveri's centrosome). As the reader will glean from the earlier pages of this chapter, I regard the substance forming the radiations about the attractive body as identical with the egg cytoplasm. — June, 1895.

The section seen in Figure 15 shows that cleavage has progressed more rapidly from the ventral than from the dorsal surface. This is to be explained by the richer supply of protoplasm on the ventral surface.

A study by reconstruction or otherwise of a series of sections through an egg in this stage *invariably* shows that cleavage has also progressed with unequal rapidity from the two *ends* of the embryo.

That end at which cleavage is more advanced is destined to become the posterior end. In this case also the inequality in rate of cleavage is attended (probably caused) by an inequality in the distribution of protoplasm. The protoplasmic cap of the ventral hemisphere is always thicker at the future posterior end of the embryo than at the anterior end, and as the first cleavage plane cuts the egg, this accumulation of protoplasm migrates in between the two blastomeres, its presence probably being the accelerating force in the separation of the blastomeres.

After the first cleavage is completed, the protoplasm, which had migrated in between the blastomeres, again returns to the surface and takes up a very definite position on the adjacent faces of the blastomeres just below the equator of the egg. (See Plate III. Fig. 17, $x$.)

This region appears in the living egg as a clear area, and marks the spot where arise later the small flattened posterior cells found so useful in orientation by Van Beneden et Julin and others. That this clear area *is* the region of their formation I have been able to establish by continuous observations of the living egg, controlled and completely supported by the study of preparations. *The thickened spot in the protoplasmic cap of the ventral hemisphere at the beginning of cleavage*, which seems to determine the posterior end of the embryo, *I believe to be caused by the entrance of the spermatozoön.* It is evident that the spermatazoön, unless it enters exactly at the ventral pole of the vertical axis, must lie upon entrance nearer to one end of the egg than to the other, supposing that it is in the median plane and ventral hemisphere of the embryo.

The *nearer* end, I believe, becomes the posterior end of the embryo, and is determined for that fate by the accumulation of protoplasm in the region of entrance of the spermatazoön. It is impossible to say in any particular case exactly where the spermatazoön has entered the egg, for its presence there cannot be detected until it has begun to form a yolk-free area in the egg. However, I have never observed a case in which the spermatozoön did not give evidence from its position of having entered the egg excentrically with reference to the lower pole of the vertical axis. Hence I conclude that cases of entrance *at* that pole, if they occur, are extremely rare.

### Summary on Polarity of the Egg.

(1) *The dorso-ventral axis of the embryo is predetermined in the egg before fertilization; the polar globules invariably form at its dorsal pole.*

(2) *The spermatozoön may enter the egg at any point on its ventral hemisphere, that point probably determining, however, the median plane and posterior end of the embryo.*

(3) If we adopt the commonly employed terms *animal* and *vegetative* for the two poles of the unfertilized egg, we must call the ventral the animal pole, and the dorsal the vegetative pole. For it is the *ventral* half of the egg which contains a richer supply of protoplasm, and which consequently cleaves more rapidly and becomes the ectodermal side of the embryo; whereas the dorsal half of the egg contains less protoplasm, cleaves less rapidly, and forms the endodermal portion of the embryo.

(4) We may say, accordingly, that *the form changes accompanying maturation occur, in Ciona at least, and presumably in Ascidians in general, at the pole of the egg opposite to that at which they occur in Amphioxus,* and, so far as known, in all other animals producing eggs with polar differentiation; for the changes connected with maturation are uniformly reported to take place at the *animal*, i. e. at the more richly protoplasmic pole, whereas in Ciona they take place at the vegetative pole.

## VI. CELL LINEAGE OF THE EMBRYO.

The statement made in the preceding paragraph presents a condition of affairs so directly contrary to that found in other groups of animals, as well as to what has been assumed by all previous writers to be the case in Ascidians, that it requires the presentation of unmistakable evidence in its support. Such evidence I have to offer, both from the study of the living egg and from that of preparations. Before passing, however, to the consideration of this evidence, a word of explanation is necessary concerning the system of nomenclature to be employed.

### 1. Nomenclature.

In any extended work on cell lineage it is desirable to have some system of naming the individual cells which will indicate readily the exact history of each, — from what part of the matured ovum it has been derived, by how many divisions it is removed from the ovum, and from what other cells these divisions have separated it. In this paper I shall follow with some modifications the system introduced by Kofoid ('94) in his work on Limax.

1. Each cell will be designated by a letter with two exponents.

2. The letter indicates the quadrant of the egg from which the cell in question has been derived, or in other words that cell of the 4-cell stage from which it is descended. Viewing the egg from the ventral or animal pole (the one *opposite* that at which the polar cells are formed), the left anterior quadrant is *A*, the right anterior *B*, the right posterior *C*, and the left posterior *D*. In dorsal views, *A* and *D* are of course the right quadrants, and *B* and *C* the left.

3. The first exponent indicates the *generation* to which a cell belongs; that is, the number of cell divisions by which it is removed from the ovum. The ovum is generation one, the 2-cell stage two, the 4-cell stage three, etc. (See the Table of Cell Lineage on page 275.)

4. The second exponent indicates the *number* of a cell in a generation, the cells of each quadrant being numbered independently from the animal toward the vegetative pole.[1] If in any case two cells of common descent lie in an equatorial position, that one which is nearer the sagittal plane is given the lower numeral.

To ascertain the designation of the mother cell of any particular cell, its *first* exponent must be diminished by one; and its *second* exponent, if an even number, must be divided by two, but if an odd number it must first be increased by one and then divided by two.

In order to determine the daughter cell of a particular cell, simply reverse this process; that is, increase the first exponent by one, and double the second exponent. To determine the other daughter cell, diminish this second exponent by one. For example, the daughter cells of $a^{5\cdot4}$ are $a^{6\cdot8}$ and $a^{6\cdot7}$.

## 2. Cleavage.

### A. Early Stages of Cleavage.

### (a) *To 24-cell Stage.*

Figures 19–26 (Plate IV.) show eight views of a living egg, drawn by means of an Abbé camera lucida at successive stages, the egg remaining undisturbed in position under the microscope throughout the period of observation. The left side of the egg is, as I shall show, towards the observer. In Figure 19 the process of maturation is seen to be completed, the polar globules lying in a slight depression on the dorsal surface of the egg. The 2-cell stage is shown in Figure 20. The 4-cell stage is seen in Figure 21 to be approaching, and has been reached at the stage shown in Figure 22. The two blastomeres on the side toward the observer appear to be of equal size, the other two are hid from sight. A view of the egg immediately after the next division is shown in Figure 23; the appearance nine minutes later is shown in Figure 24. These both represent the 8-cell stage, and show that *the four cells which lie nearest the polar globules are smaller than those more remote.* They also show that division has occurred in such a manner that the pair of cells occupying the upper right-hand corner of the figure is in contact with the diagonally opposite pair of cells in the lower left-hand corner of the figure, whereas the pair of cells in the upper left-hand corner is entirely separated from that diagonally opposite it. This arrangement is due to no accidental shoving of cells one over another, but is found *invariably* occurring at the 8-cell stage. The diagonally opposite cells which are in contact form respectively the posterior dorsal and anterior ventral portions of the embryo. This arrangement of the cells of the 8-cell stage has up to the present time been overlooked by all writers on tunicate embryology except Chabry ('87). He both distinctly recognized and clearly figured it. (See his Planche XVIII. Fig. 9.) But, as I pointed out in a previous paper ('94), that hemisphere of the egg which he, following Van Beneden et Julin, called *dorsal,* was really the *ventral* hemisphere, so that he wrongly calls the cells in contact the *anterior* dorsal and *posterior* ventral. If we correct his naming of the hemispheres, his observations on Ascidiella are brought into complete agreement with mine on Ciona regarding this point. In both cases the posterior dorsal and anterior ventral cells of the 8-cell stage are in contact. Though Seeliger ('85) apparently overlooked the fact, his figures (Taf. I. Figs. 7, 8, and 10), when their orientation is corrected as I ('94) have shown to be necessary for other reasons, present precisely the same arrangement of cells in the 8-cell stage of Clavelina. This condition is therefore probably of general occurrence among the simple and social Ascidians.

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[1] In gastrulation, the cells about the vegetative pole are depressed to a lower level than the margin of the blastopore. In naming cells it is considered that the vegetative pole is also depressed at that period, and lies constantly on the dorsal surface at the common point of meeting of the cells derived from the four quadrants.

The 16-cell stage immediately after its formation is shown in Plate IV. Fig. 25, and half an hour later in Figure 26. In the stage represented by Figure 26, spindles, directed as indicated by the arrows, were already visible in the large cells, occupying the lower half of the figure, though none had yet appeared in the smaller cells composing the upper half of the figure. This fact foreshadows an earlier division on the part of the cells of the lower hemisphere, which would lead to a stage of twenty-four cells. Such a stage was figured in my preliminary paper ('94, Plate I. Figs. 1 and 2; here reproduced in Plate IX. Figs. 51 and 52), and it was there demonstrated that the hemisphere in which division is earliest, as the egg passes from the 16-cell stage, becomes later the ventral or ectodermal hemisphere of the embryo.

Accordingly the series of observations illustrated by Figures 19–26 goes to prove that the four larger cells of the 8-cell stage, which are more remote from the polar globules, form the ventral or ectodermal half of the embryo, whereas the four smaller cells, on which the polar globules rest, become the dorsal or endodermal half of the embryo.

The same thing is shown by Figures 27–34 (Plates V. and VI.), a series of drawings of an egg viewed from its anterior end. In Figures 27–29 are seen successive phases of the 2-cell stage. Figure 30 shows the 4-cell stage, and Figures 31 and 32 two phases of the 8-cell stage. At the 8-cell stage in this series, as well as in the series previously examined, the four cells nearest the polar globules are smaller than the other four; they will form, as we shall see, the dorsal hemisphere. There has been no shoving of cells across the median plane, but shoving has occurred among the cells of the right and left halves of the embryo separately, as was seen also at this stage in the series previously examined. (See Plate IV. Fig. 23.) According to the rule already stated, we should find in contact with each other the diagonally opposite pairs of cells which are to form respectively the posterior dorsal and anterior ventral portions of the embryo; while the other two pairs of cells should be completely separated. If this is true in the case before us (Figs. 31 and 32), we are looking at the anterior end of the embryo, for the pair of *ventral* cells *nearest* the observer is seen to be in contact with the most *remote* pair of *dorsal* cells.

Figure 33 (Plate VI.) shows the 16-cell stage, and Figure 34 the 24-cell stage in process of formation. In this egg also the cells of the hemisphere most remote from the polar globules were first to divide in passing from the 16-cell stage. Those of the other hemisphere divided in this case about twelve minutes later. Therefore *by this series also the hemisphere more remote from the polar globules is shown to be the ventral or ectodermal.* That one is looking in this series at the anterior end of the embryo, as already suggested, and not at the posterior end, is shown by a comparison of Figure 34 (Plate VI.) with Figure 51 (Plate IX.), both of which represent the 24-cell stage. The posterior end of the embryo is seen in Figure 51 to be marked by a noticeably small pair of cells, the like of which does not appear in Figure 34, but may be supposed to lie hidden from view at the more remote end of the embryo. Moreover, the cells $A^{6.1}$, $A^{6.2}$, $B^{6.1}$, $B^{6.2}$ of Figure 51, which are situated at the anterior end of the embryo, correspond well in size with the four cells nearest the observer in Figure 34. Therefore the rule previously stated for the orientation of the 8-cell stage is exemplified in this series also.

In Figures 45–50 (Plate VIII.) is shown another series of drawings illustrating what has been said regarding the clear protoplasmic region ($x$) which throughout cleavage marks the posterior end of the embryo. In this series one looks down obliquely on the dorsal surface of the embryo from its posterior end. The polar globules are not visible, for the reason that they do not come into profile at the margin of the egg, a circumstance which is necessary for an exact determination of their position.

In Figure 45, a 2-cell stage, the clear region appears in each blastomere at $x$. During each successive cell division it bulges out as represented in Figure 46, and again in Figure 47, just as if it were the most plastic portion of the egg and responded most readily to the internal tension which accompanies cell division. Such indeed is probably the case, for this region is free from yolk granules, consisting of protoplasm only, as has been already pointed out.

In Figure 48, the 8-cell stage is seen to be completely formed. Applying our rule for the orientation of the egg at this stage, we decide that the pair of cells occupying the centre of the figure and nearest to the observer is to form the posterior dorsal portion of the embryo; for (1) it belongs to the set of four smaller cells formed by the first equatorial plane of cleavage, and (2) it is in contact with the diagonally opposite pair of cells of the other hemisphere. The sequel justifies our conclusion. Figure 49 represents the 16-cell stage, and Figure 50 the 24-cell stage.[1] In Figure 50 it is seen that the small posterior cells of the ectodermal hemisphere, unmistakably identical with $C^{6.3}$ and $D^{6.8}$ of Figure 51 (Plate IX.), have appeared just where the clear portions forming prominences at the time of cell division have all the time been. These portions have become a part of the small cells in question, which contain less yolk than any other cells of the egg at this stage, and subsequently cleave less rapidly than any other cells of the ventral hemisphere. The persistence of this clear polar region in stages later than that of 24 cells was shown in certain figures of my preliminary paper (reproduced in Plate IX. Figs. 54 and 55). It finally passes into the small flattened cells $C^{7.5}$, $D^{7.5}$ (Plate XI. Fig. 71), of whose later history we shall have more to say.

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[1] It will be observed that between the stages represented in Figures 49 and 50 there has been a slight rotation of the egg, so that the latter figure exhibits an exactly dorsal view instead of an obliquely dorsal one.

Chabry ('87) observed in Ascidiella at the beginning of the 8-cell stage the formation of polar prominences such as I have described, and spoke of them as a sure means of orienting the egg at this stage. On page 203 he says: "Il est encore une marque propre aux cellules P et *P* [$D^{4.1}$, $C^{4.1}$] que permet de les distinguer de toutes les autres, elle consiste en une petite saillie en forme de mamelon, saillie qui est dirigée horizontalement en arrière et que montrent les figures 2 et 23 de la planche XVIII. Cette saillie n'est visible qu'au début du stade VIII. [8-cell] et surtout durant la segmentation qui produit P et *P* [$D^{4.1}$, $C^{4.1}$]." Apparently Chabry overlooked the formation of the prominences at other than the 4- and 8-cell stages, and failed to recognize their true significance. For he explains them as merely foreshadowing the form and direction of the next cell division, and as referable to a supposed general phenomenon, which, stated in his own words, is as follows: "Que les blastomères ont à l'instant où ils viennent de se produire et mieux encore *durant leur individualisation* des formes spécifiques qu'ils perdent peu d'instants après. Ces formes spécifiques paraissent être en rapport avec les segmentations dont ces blastomères seront plus tard le siège . . . la segmentation a donc lieu dans tous les cas, perpendiculairement au plus grand axe que possédait le blastomère durant son individualisation."

It is hardly necessary, I suppose, to say anything at this late day in refutation of Chabry's generalization. My own observations indicate that cells tend to assume at the time of their formation ("individualisation") a *spherical* form,[1] if they are homogeneous in structure, and that the departure from an evenly rounded contour at the posterior end of the ventral hemisphere is explicable by the presence there of a region peculiar in its constitution, containing as it does less yolk than the other superficial portions of the egg.[2]

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[1] Mutual pressure of cells may modify this form, in which case the direction of the next division may perhaps be predicted, as Chabry states, at the time of the "individualisation" of cells. For, *other things being equal*, it is true that the spindle arises in the longest axis of the cell.

[2] I am aware that Van Beneden et Julin ('84) have offered an entirely different explanation for certain phenomena probably related to those under discussion, which they observed in the cleaving egg of Clavelina. Their explanation implies

Let us examine still another series of drawings (Figs. 35–42, Plates VI. and VII.) made from the living egg, which in this case is viewed from the ventral side and a little obliquely. The polar globules of course are not seen, since they lie on the opposite side of the egg. Neither is the point of view a favorable one to bring the posterior polar regions clearly into profile as in the series last examined.

Figure 35 (Plate VI.) shows the 4-cell stage; Figures 36 and 37, successive views of the 8-cell stage; and Figure 38, a 12-cell stage, the four cells of the ventral hemisphere having divided in this case a little earlier than those of the dorsal hemisphere. This is unusual, for the difference in rate of cleavage of the cells of the two hemispheres commonly first appears, as we have seen in the three series previously examined, in passing from the 16-cell stage to one of 24 cells.

Figure 39 (Plate VII.) gives a view of the egg five minutes after the stage shown in Figure 38 had been reached. It represents the 16-cell stage. A drawing made five minutes later still is shown in Figure 40, and one made ten minutes after that is shown in Figure 41.

In the last mentioned figure, the cells of this uppermost hemisphere are seen to have again become rounded in outline preparatory to the next cell division. Spindles are already visible in them, as indicated by the arrows, those last to appear being the ones in the small cells ($C^{5.2}$, $D^{5.2}$) at the lower margin of the figure. The subsequent division was about a minute later in these two cells than in the others of the same hemisphere; this is regularly the case in the cell division which leads to the 24-cell stage.

Figure 42, the last of the series, will be at once recognized, by one who has read my preliminary paper, as a ventral view of the 24-cell stage. (Cf. Plate IX. Fig. 51.) The posterior end is clearly marked by the small cells $C^{6.3}$, $D^{6.3}$. A re-examination of Figures 36 and 37 (Plate VI.) shows that the rule previously stated for orienting the egg at the 8-cell stage is again exemplified in the case of this series, for in

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the existence during karyokinesis of *astral fibres* which attach to the cell wall at particular points and by their contraction depress its surface.

Such an explanation seems to me inadequate, at least for this case; first, because I have seen no evidence of the existence of astral *fibres* in karyokinesis; secondly, because at successive cleavages the prominences appear in the same structurally peculiar region, whether the karyokinetic spindle is directed *toward* that region — as the explanation of Van Beneden et Julin would imply — or not (see Plate VIII. Fig. 47); thirdly, because astral fibres, if present, should appear in every blastomere at karyokinesis, but I have been able to discover these peculiar prominences only in the particular regions already described.

Figures 36 and 37 we see in contact cells which we know, from an examination of Figure 42, eventually become the anterior ventral and posterior dorsal portions of the embryo.

We have now followed the cleavage cell by cell to the 24-cell stage. We have seen that cleavage is from the very beginning bilateral, and progresses in a very definite manner and at a very definite rate. This we shall find is true in the further development of the egg, even until the complete closure of the blastopore. Wilson ('94) observed that the cleavage of Amphioxus showed all gradations between a perfectly radial, a bilateral, and even a spiral form; and he raised a query whether the same might not be found to be true for Ascidians. In Ciona at least this does not seem to be the case. I have never observed an instance of deviation from the regular mode of cleavage described in the foregoing paper, unless one so construes the occasional very slight difference in the time of cleavage of the cells of the two hemispheres in passing from the 8-cell stage, a matter to which allusion was made on page 232. No rotation of the cells of one hemisphere over those of the other even in the slightest degree has ever been observed. In having a perfectly definite and stereotyped manner of cleavage, the ascidian egg resembles more closely the egg of Annelids, Mollusks, and the great majority of Invertebrates, than it does that of Amphioxus and the Vertebrates, notwithstanding that the *end product* of cleavage shows unmistakably the now generally admitted closer affinity of Tunicates with the latter group of animals.

It remains to call attention to some of the internal phenomena accompanying the early cleavage stages. The first cleavage spindle arises, as has been stated, not far from the centre of the egg. (See Plate III. Fig. 14.) As its first cleavage is nearing completion, however, the attraction spheres and nuclei begin to move toward the dorsal surface o the egg, *away from* its more richly protoplasmic (animal) pole, from which the plane of separation cuts in more rapidly. (See Plate III. Fig. 15.) The attraction sphere of each blastomere grows more diffuse as the nuclei pass into a resting condition; it then elongates in a horizontal direction and parallel to the first plane of cleavage, and finally divides. The parts separate and the nucleus moves out to a position between them. (See Plate III. Fig. 16.) By this time the attraction spheres and nuclei unmistakably lie closer to the dorsal (maturation) surface of the egg. (Plate III. Fig. 16; cf. Plate IV. Figs. 20, 21, and Plate V. Figs. 27–29; also Van Beneden et Julin's ['84] Figs. 2 and 4 *b*, Planche VII., remembering that dorsal and ventral are reversed in Van Beneden et Julin's figures.) The yolk-free protoplasm trails downward from the attraction spheres forming a sort of crescent in each blastomere. (See Plate III. Fig. 16.)

During the second and third cleavages the nuclei remain somewhat nearer the dorsal (vegetative) pole. (Plate IV. Figs. 20–22, and Plate V. Fig. 30; cf. Van Beneden et Julin's ['84] Figs. 4 *b* and 5, Planche VII.) It follows naturally that when the 8-cell stage is formed by the first equatorial plane of cleavage (third cleavage), an inequality is observed in the size of the newly formed blastomeres, the four nearer to the *dorsal* pole being *smaller* than their sister cells, though the latter are richer in protoplasm. (See Plate IV. Fig. 23, and Plate III. Fig. 18.)

### (*b*) *Summary on Early Cleavage Stages.*

1. The future posterior end of the embryo is marked at the 2-cell stage by an accumulation of protoplasm free from yolk in each blastomere at contiguous regions. This accumulation persists throughout cleavage, and forms at each cell division a pair of protuberances beyond the general contour of the blastomeres.

Subsequently to the 8-cell stage, in each of the two blastomeres in which these accumulations lie, the spindle at three successive cell divisions is directed *toward* the protoplasmic accumulation of that cell and lies *nearer* to it than to the opposite side of the cell. In consequence the newly formed cell, which contains the region in question, is in each case *smaller* than its sister cell. (Cf. $D^{5.1}$ and $D^{5.2}$, Fig. 38, Plate VI.; $D^{6.2}$ and $D^{6.3}$, Fig. 51, Plate IX.; and $D^{7.5}$ and $D^{7.6}$, Fig. 62, Plate X.)

At each of these divisions also cleavage occurs *later* in the cells containing the protoplasmic accumulations than in their sister cells.

2. The first cleavage plane is vertical, and passes through the point of formation of the polar globules. It coincides with the future median plane of the embryo, and divides the egg into two blastomeres equal in size and similar in every particular. They form respectively the right and left halves of the embryo. The fate, as just stated, of the first two blastomeres of the ascidian egg was first pointed out in the case of Clavelina by Van Beneden et Julin ('84).

3. The second cleavage plane is also vertical, and at right angles to the first. Like the first, it passes through the point of formation of the polar globules. It divides the egg into four blastomeres, among which no difference of size can be recognized.

4. The third cleavage plane is at right angles to both the preceding, i. e. equatorial in position. It separates four smaller cells lying nearer to the polar globules and more abundantly supplied with yolk, from four larger ones more remote from the polar globules and richer in protoplasm. The former are destined to give rise to the dorsal or endodermal hemisphere of the embryo; the latter, to the ventral or ectodermal hemisphere.

The protoplasmic accumulations mentioned under paragragh 1 always fall in the posterior pair of cells of the ventral hemisphere (viz. $D^{4.1}$, $C^{4.1}$) close to its line of contact with the dorsal hemisphere. This pair of cells is never in contact with the anterior pair of cells of the dorsal hemisphere, but the *anterior* pair of cells of the ventral hemisphere (viz. $A^{4.1}$, $B^{4.1}$) is *invariably* in contact with the posterior pair of cells of the dorsal hemisphere (viz. $c^{4.2}$, $d^{4.2}$).

The fact just stated affords a ready and unfailing means of orienting the 8-cell stage. This was recognized by Chabry in the case of Ascidiella, and is shown by an examination of Seeliger's figures to be equally true for Clavelina. It probably holds good among all the simple and social Ascidians.

5. The 16-cell stage is usually reached by simultaneous divisions in both hemispheres. Sometimes, however, the cells of the ventral hemisphere at this cleavage divide sooner than those of the dorsal hemisphere, thus giving rise to a 12-cell stage, but this very soon changes to a 16-cell stage by the cleavage of the cells of the dorsal hemisphere.

6. As the egg passes from the 16-cell stage, cleavage *invariably occurs earlier* in the cells of the ventral hemisphere, i. e. the descendants of the four larger cells of the 8-cell stage, than it does in the cells of the dorsal hemisphere. A 24-cell stage results, in which the cells of the ventral hemisphere, being twice as numerous as those of the dorsal hemisphere, cover more surface and begin the process of overgrowth (epiboly), forcing the cells of the dorsal hemisphere into a somewhat columnar form. (See Plate VII. Fig. 44.)

## B. Later Stages of Cleavage.

### (a) *From 24-cell to 46-cell Stage.*

The 24-cell stage was taken as the point of departure in my preliminary paper ('94), and the cell lineage was traced in detail through a stage of 46 cells. I shall not repeat except in the form of a brief *résumé* what was there said regarding those stages, but shall content myself with reproducing (in Plate IX.) the figures of Plate I. accompanying that paper, which were executed to illustrate this period of the developmental history. These figures present dorsal and ventral views of the 24-cell stage (Plate IX. Figs. 51 and 52), the 32-cell stage (Figs. 53 and 54), and the 46-cell stage (Figs. 55 and 56).

The interpretation, as given in my preliminary paper, of the lineage through the 46-cell stage rested upon the strongest possible evidence, viz. the observation of karyokinetic figures for every cell division which was represented as having occurred. Moreover, it was shown that these observations made it possible to reconcile the conflicting statements of others who had studied the cleavage of the ascidian egg. Such excellent observers as Van Beneden et Julin, on the one hand, and Seeliger, on the other, held contrary opinions as to which was the dorsal side and which the anterior end of the embryo in its early stages in one and the same genus, Clavelina.

It was shown in my paper, both from an examination of the authors' own figures and from a comparison with the lineage of Ciona, that their conflicting statements arose from a fundamental error on the part of each, Van Beneden et Julin being correct in their determination of the *ends* of the embryo, and Seeliger in his determination of the dorsal and ventral *surfaces* of the early stages. Upon correcting these mistakes, it was found that the observations of the writers mentioned were brought into harmony, and were then in agreement with my own observations on Ciona.

In order to demonstrate that I had correctly determined the dorsal and ventral faces of the egg for the 46-cell and earlier stages, in contradiction to the interpretation of Van Beneden et Julin, I figured a single older stage described as one of 66 cells (Castle '94, Plate II. Figs. 11 and 12). Its presentation was intended to bridge the gap between the 46-cell stage and gastrulation. This purpose it fulfilled, for it showed gastrulation already commenced, and so proved beyond question which was to be the oral (dorsal) and which the aboral (ventral) surface.

A desire to give completeness to my figures led me to state the *lineage* of this stage as I then understood it. I have since found, from the study of more complete series of embryos than I had at that time secured, that I was mistaken as to the time of cell division in one pair of cells ($C^{7.8}$, $D^{7.8}$, Fig. 56, Plate IX.). I supposed it had already occurred at the stage represented in Figures 11 and 12 (Plate II.) of my former paper. Consequently the lineage there given for this stage is incorrect. Though this fact does not affect the main conclusions of my preliminary paper, it necessitates modification of several minor statements, as will be indicated in detail later.

The 24-cell stage, it has been seen, arises from the 16-cell stage by an earlier division on the part of the cells of the ventral hemisphere than occurs in those of the dorsal hemisphere. Accordingly, we find that at the 24-cell stage the ventral hemisphere consists of sixteen cells, whereas the dorsal hemisphere is made up of only eight. These eight are compressed into a columnar form by the overgrowth of the cells of the ventral hemisphere already begun. (See Plate VII. Fig. 44.) Their nuclei lie in a superficial position, while their deep ends are heavily laden with unassimilated yolk. They retain this columnar form up to and throughout gastrulation. In number, they are soon brought up to an equality with the cells of the ventral hemisphere by division, which leads to the 32-cell stage (Plate IX. Figs. 53 and 54) and places all the cells of the egg in the sixth generation.

Presently the cells of the ventral hemisphere again anticipate in division those of the dorsal hemisphere, this time by a still longer interval. Among the cells of the ventral hemisphere differences in the time of division could, as we have seen, be detected at the preceding cleavage. At the present cleavage the differences become more pronounced. In particular, the small posterior cells, $C^{6.3}$, $D^{6.3}$ (Plate IX. Figs. 53 and 54), divide enough later than their fellows to allow us to recognize a 46-cell stage (Plate IX. Figs. 55 and 56), made up as follows: —

Ventral hemisphere, 28 cells in the seventh generation,
2 cells ($C^{6.3}$, $D^{6.3}$) in the sixth generation.
Dorsal hemisphere, 16 cells in the sixth generation.
46

When the two small cells $C^{6.3}$, $D^{6.3}$, divide, which they do earlier than the cells of the dorsal hemisphere, a stage of forty-eight cells is reached, all the cells of the ventral hemisphere (thirty-two in number) being in the seventh generation, and those of the dorsal hemisphere (sixteen in number) being in the sixth generation. Such a stage is shown in Plate X. Figs. 57 and 58.

### (b) *48-cell Stage.*

The embryo shown in Figures 57 and 58 has a vertical axis the length of which is equal to that of its antero-posterior axis, if not greater. Accordingly it has been found easier to maintain this axis in a horizontal position, and hence more convenient to represent the egg as viewed from the anterior and posterior ends respectively, rather than from the dorsal and ventral surfaces, as in most of the other stages figured. This stage (48-cell) is made up as follows: —

Ventral hemisphere, 32 cells in the seventh generation.
Dorsal hemisphere, 16 cells in the sixth generation.
—
48

It will be observed that the cells of the ventral hemisphere, though all in the seventh generation, are not all equally advanced in their preparations for division, which evidently is again about to set in. For while the cells occupying the centre of the ventral hemisphere, or, in other words, lying nearest to the animal pole of the egg, are about to pass into the next generation, the cells occupying the margin of the ventral hemisphere, and more remote from the animal pole, contain nuclei entirely quiescent, like those seen in the cells of the dorsal hemisphere. This is contrary to the statement made in my preliminary notice ('94), in which I said that at this division those cells of the ectodermal hemisphere which were marginal and in contact with cells of the endodermal hemisphere were *first* to divide. This erroneous statement arose from the wrong interpretation given to Figures 11 and 12 ('94 Plate II.) in describing the cell lineage of that stage, a matter to which attention has already been directed.

In the embryo shown in Plate X. Figs. 57 and 58 (48-cell stage) one may readily distinguish three regions, each composed of sixteen cells. The first region is the dorsal hemisphere, with its sixteen cells all in the sixth generation ($a^{6.5}$–$a^{6.8}$, $d^{6.5}$–$d^{6.8}$, and the corresponding cells in quadrants $B$ and $C$). These cells are destined to form the endoderm of the larva, the chorda, and a portion of the mesoderm. The second group of sixteen cells occupies the centre of the ventral hemisphere ($A^{7.1}$, $A^{7.2}$, $A^{7.3}$, $A^{7.5}$, $A^{7.7}$, $D^{7.1}$, $D^{7.2}$, and $D^{7.3}$, with the corresponding cells in quadrants $B$ and $C$). They are in the seventh generation, but already contain spindles, showing that they are soon to pass into the eighth generation. This group of cells will form the ectoderm of the larva. The remaining sixteen cells of this embryo, also belonging to the ventral hemisphere, form the third group ($A^{7.4}$, $A^{7.6}$, $A^{7.8}$, and $D^{7.4}$–$D^{7.8}$, with the corresponding cells in quadrants $B$ and $C$). They too are in the seventh generation, but their nuclei are quiescent, showing that these cells will be later in dividing than the other cells of the ventral hemisphere. They are arranged in an equatorial band between the other two groups of cells. This band is interrupted at only one point on each side of the embryo, where a single cell ($A^{7.5}$, $B^{7.5}$) of the ectodermal group reaches up into contact with the cells of the dorsal hemisphere. From the equatorial band just described are derived chiefly nerve cells and mesoderm cells.

### (*c*) *64-cell Stage.*

The completion of the divisions foreshadowed by spindles in the ectodermal group of cells of the stage last discussed (Plate X. Figs. 57 and 58) doubles the number of cells in that group, and brings the number in the entire embryo up to sixty-four, distributed as follows.

Ventral hemisphere (designated by the letters *A*, *B*, *C*, *D*) : —
32 cells in the 8th generation = the ectodermal group.
16 " 7th " = the equatorial band.
48

Dorsal hemisphere (designated by *a*, *b*, *c*, *d*) : —
16 cells in the 6th generation.
64

Such a stage is shown in Plate X. Figs. 59 and 60, the former representing a ventral and the latter a dorsal view. The egg has again assumed the flattened form which it had at the 32-cell stage.

Examining first the ventral surface (Fig. 59), we see that the divisions foreshadowed in the 48-cell stage (Figs. 57 and 58) have in every instance occurred in a direction perpendicular to that of the spindle in the mother cell, though a slight displacement is in some cases appearing among the daughter cells, on account of the mitoses arising in the equatorial band. The cells of the ectodermal group, on account of their recent division, now number thirty-two, as many as are found in both the other groups put together. They are in the eighth generation, one generation in advance of the cells of the equatorial band, and two generations in advance of the cells of the dorsal hemisphere. They are $A^{8.1}$–$A^{8.6}$, $A^{8.9}$, $A^{8.10}$, $A^{8.13}$, $A^{8.14}$, and $D^{8.1}$–$D^{8.6}$, together with the corresponding cells in quadrants *B* and *C*.

The equatorial band is, as at the last stage, composed of sixteen cells all in the seventh generation, but six of them (three on each side of the median plane, Fig. 60, $A^{7.4}$, $A^{7.8}$, and $D^{7.4}$) now show signs of approaching division. Four of these mitotic cells form the anterior segment of the equatorial band, and are destined to produce a considerable portion of the nervous system of the larva. (See Fig. 60, $A^{7.4}$, $A^{7.8}$, $B^{7.4}$, and $B^{7.8}$.) The two remaining mitotic cells of the equatorial band are situated laterally one in each of the posterior quadrants (Figs. 59 and 60, $D^{7.4}$, $C^{7.4}$).

The ten remaining cells of the equatorial band all contain resting nuclei. Eight of these cells are grouped at the extreme posterior end of the equatorial band in a region where, from the 16-cell stage on, we have found cleavage to be more tardy than in any other part of the ventral hemisphere. These eight cells are $D^{7.5}$, $D^{7.6}$, $D^{7.7}$, $D^{7.8}$, and the corresponding cells in quadrant *C*. (Figs. 59 and 60. Compare Fig. 57.) The two remaining cells of the equatorial band which still show no signs of division are $A^{7.6}$ and $B^{7.6}$ (Fig. 60), situated about midway between the anterior and posterior ends of the embryo.

Of the sixteen cells comprising the dorsal hemisphere (Fig. 60), six, which lie in contact with the equatorial band ($a^{6.5}$, $a^{6.7}$, $d^{6.6}$, with their mates in quadrants *B* and *C*), are in mitosis. Four of them, the most anterior of the cells of the dorsal hemisphere, lie in a transverse row across the dorsal surface of the embryo (Fig. 60, $a^{6.7}$, $a^{6.5}$, $b^{6.5}$, and $b^{6.7}$). They will ultimately form the greater portion of the chorda. We will call them the *anterior chorda fundament.* The two other mitotic cells of the dorsal hemisphere are $d^{6.6}$ and $c^{6.6}$, in the posterior half of the embryo (Fig. 60). The spindles in these cells are directed obliquely forward, upward, and outward, so that, taking into consideration the superficial position of the nuclei of the dorsal hemisphere, we may predict that the coming division will result in cutting off in each case a smaller more superficial cell from a larger cell extending deeper; the small cell will also lie anterior and lateral to its sister cell. The unequal divisions in these two cases will separate cells of unlike fate; the two smaller cells will constitute the *posterior chorda fundament,* the two larger ones will form mesoderm.

The ten remaining cells of the dorsal hemisphere (Fig. 60, $a^{6.6}$, $a^{6.8}$, $d^{6.5}$, $d^{6.7}$, $d^{6.8}$, and the corresponding cells in quadrants *B* and *C*) show as yet no signs of division. They are grouped about the vegetative pole of the egg, the point of origin of the polar cells, and *will form the whole of the definitive endoderm of the larva, and nothing else.*

### (*d*) *76-cell Stage.*

Upon the completion of division in the twelve mitotic cells of the embryo represented in Plate X. Figs. 59 and 60, a stage of seventy-six cells would be reached. An embryo in this stage is shown in Plate X. Figs. 61 and 62. It contains in the

Ventral hemisphere (designated by the letters *A, B, C, D*):
32 cells in the eighth generation = the ectodermal group.
12 cells in the “ “ ⎫ = the equatorial band.
10 cells in the seventh “ ⎭
54 —

Dorsal hemisphere (designated by *a, b, c, d*): —
2 mesoderm cells in the seventh generation.
10 chorda cells in the “ “
10 endoderm cells in the sixth “
22 —
76

The ectodermal group of the ventral hemisphere contains the same number of cells as at the 64-cell stage, viz. thirty-two, — sixteen on each side of the median plane, ten of them being derived from an anterior quadrant ($A$), six from a posterior quadrant ($D$). They cover nearly the entire ventral surface of the egg. (See Plate X. Fig. 61, $A^{8.1}-A^{8.6}$, $A^{8.9}$, $A^{8.10}$, $A^{8.13}$, $A^{8.14}$, and $D^{8.1}-D^{8.6}$, as well as the corresponding cells in the right half of the figure.) All the cells of this group are in the eighth generation.

The equatorial band now contains six more cells than at the 64-cell stage, in consequence of the completion of divisions foreshadowed at that stage in the cells $A^{7.4}$, $A^{7.8}$, $B^{7.4}$, $B^{7.8}$, $C^{7.4}$, and $D^{7.4}$ (Fig. 60). It now consists of twenty-two cells, which, in passing from the posterior end forward, are $D^{7.5}$, $D^{7.6}$, $D^{7.7}$, $D^{7.8}$, $D^{8.7}$, $D^{8.8}$, $A^{7.6}$, $A^{8.16}$, $A^{8.15}$, $A^{8.8}$, and $A^{8.7}$, with the corresponding cells in quadrants $B$ and $C$ (Fig. 62). Six of the cells on each side of the median plane are derived from a posterior and five from an anterior quadrant. Signs of approaching division have at this stage become visible in four of the cells of this equatorial band, viz. $A^{7.6}$, $B^{7.6}$, $D^{7.7}$, and $C^{7.7}$. In the case of the first two cells mentioned the spindles stand vertically (cf. Plate X. Fig. 67, $A^{7.6}$); in the other two cells ($C^{7.7}$, $D^{7.7}$) the spindles are nearly horizontal in position, though their antero-lateral ends lie at a slightly higher level than the opposite ends.

There are only six cells remaining in the equatorial band which neither have passed into the eighth generation nor show any signs of immediately doing so. They are grouped at the posterior end of the embryo, which has been repeatedly pointed out as the region of slowest cleavage among the cells of the ventral hemisphere. The six cells in question are $D^{7.5}$, $D^{7.6}$, $D^{7.8}$, and the corresponding cells in quadrant $C$ (Fig. 62).

Although for convenience I shall continue to use the term equatorial band, it is clear that the cells composing it are no longer strictly equatorial in position, but now lie on the flattened dorsal surface (Fig. 62). This change of position has come about in consequence of the more rapid cell division in the ventral hemisphere. How considerable the difference in rate of division has been between the cells of the two hemispheres, one readily appreciates if he stops to consider that the cells of the ventral hemisphere now number fifty-four, whereas those of the dorsal hemisphere number only twenty-two.

In the dorsal hemisphere (Fig. 62) the divisions foreshadowed by spindles at the 64-cell stage (Fig. 60) have taken place, but no new ones are approaching. The number of cells in this hemisphere is now twenty-two; twelve of them (the chorda and mesoderm cells, cf. description of Fig. 62 in the explanation of Plate X.) are in the seventh generation, and ten (the endoderm fundament), in the sixth generation, no divisions having occurred in the last named group of cells since the 32-cell stage. Of the ten chorda cells, eight derived from the anterior quadrants are arranged in a crescent-shaped band capping the anterior end of the dorsal hemisphere; they are $a^{7.9}$, $a^{7.10}$, $a^{7.13}$, $a^{7.14}$, and the corresponding cells in quadrant *B*. They form the anterior chorda fundament. The other two chorda cells, which are derived from the posterior quadrants, are $d^{7.11}$ and $c^{7.11}$. They form the posterior chorda fundament, and are at present separated from the anterior chorda cells by two cells of the equatorial band, viz. $A^{7.6}$ and $B^{7.6}$.

The sister cells of $d^{7.11}$ and $c^{7.11}$, viz. $d^{7.12}$ and $c^{7.12}$, are the sole contribution of the dorsal hemisphere to the mesoderm of the larva, for the greater part of the mesoderm is, as we shall see, derived from the equatorial band.

Among the endoderm cells it is noticeable that $d^{6.5}$ and its mate $c^{6.5}$ have been shoved forward out of their own quadrants to a position beside the endoderm cells derived from the anterior quadrants.

### (*e*) *Summary on Later Cleavage Stages.*

1. In the cleaving ovum one can recognize, in passing from the animal to the vegetative pole successive zones, in each of which cleavage takes place less rapidly than in the preceding. At the 64-cell stage (Plate X. Figs. 59, 60) there are three such zones: first, a group of thirty-two cells encircling the animal pole, all of them in the *eighth* generation; second, an equatorial zone of sixteen cells, all in the *seventh* generation; third, a group of sixteen cells encircling the vegetative pole,

all in the *sixth* generation. The first two zones are descended from the four ventral cells of the 8-cell stage, i. e. from the four cells most remote from the point of formation of the polar globules. The third zone is descended from the four dorsal cells of the 8-cell stage. The ectoderm is derived chiefly from the first zone, — that is, the zone encircling the animal pole; — the mesoderm is derived chiefly from the second zone, and the endoderm exclusively from the third zone.

This zonal arrangement persists throughout cleavage and the early stages of gastrulation, but its symmetry is at each succeeding stage disturbed to an increasing extent by the fact that cell division is less rapid at the posterior than at the anterior end of the embryo.

2. Although, as just stated, cleavage progresses with unequal rapidity at the two poles of the antero-posterior axis, as well as at those of the dorso-ventral axis, it is *equal* in rate at the two poles of the third axis of the egg, viz. the transverse. The last mentioned fact serves to maintain the perfectly bilateral form of the embryo.

The differentiation of the poles of the dorso-ventral and antero-posterior axes, the reader will recall, was already recognizable by structural cytoplasmic differences in the unsegmented ovum. *The form and rate of cleavage are therefore manifestly predetermined by the internal constitution of the ovum.*

## 3. Gastrulation.

### A. Early Stages of Gastrulation.

### (*a*) *112-cell Stage.*

An embryo a little more advanced in development than the one represented in Figures 61 and 62 (Plate X.) is shown in dorsal view in Figure 71 (Plate XI.). No new divisions have occurred in the dorsal hemisphere, which accordingly consists, as at the last stage, of twenty-two cells. In the equatorial band, the four cells which were preparing for division at the 76-cell stage (Plate X. Fig. 62, $D^{7.7}$, $C^{7.7}$, $A^{7.6}$, and $B^{7.6}$) are seen in Figure 71 to have divided, though in the case of $A^{7.6}$ and $B^{7.6}$, on account of the vertical position of the spindles (cf. Fig. 67), only the more superficial daughter cell is in each instance visible ($A^{8.12}$, $B^{8.12}$, Fig. 71). No further divisions have occurred in the equatorial band, which therefore consists at this stage of twenty-six cells, all in the eighth generation except the group of six cells arranged in crescent form at the posterior end of the embryo, viz. $D^{7.5}$, $D^{7.6}$, $D^{7.8}$, and the corresponding cells in quadrant $C$. These cells have lingered in the seventh generation later than all other cells of the ventral hemisphere.

The equatorial band as a whole has now moved to a position distinctly within the margin of the dorsal surface (Fig. 71), so that a row of cells from the ectodermal group of the ventral hemisphere has come into view outside it round almost the entire periphery of the embryo (*cf.* Fig. 62). This change has come about in consequence of additional divisions in the ectodermal group of cells, which now not only has spread over the entire ventral surface of the embryo, but is encroaching upon its dorsal surface.

Division has occurred nearly synchronously in all the cells of the ectodermal group, though somewhat sooner in those nearest the animal pole. (See Plate X. Figs. 63–70.) The strongest possible confirmation of my own observation regarding the simultaneousness of division in the cells of the ectodermal group in this period of development is afforded by Samassa's ('94) Figures 10 and 11, Taf. II. These represent respectively a dorsal and a lateral view of a stage intermediate between those shown in my Figures 62 and 71. In Samassa's Figures 10 and 11, all the cells of what I have called the equatorial band are figured as containing quiescent nuclei, except the four seen to be mitotic in my Figure 62 (Samassa's cells 3 and 6, Fig. 10). The other cells of the ventral hemisphere visible in Samassa's figures are without exception in process of division. It may accordingly be confidently assumed that at the stage shown in Figure 71 the cells of the ectodermal group of the ventral hemisphere have all passed into the ninth generation. If so, they number sixty-four; this agrees well with the approximate count which one can make from dorsal and ventral views, though it is impossible to be sure about the exact number of ectoderm cells lying at this stage in an equatorial position between the dorsal and ventral surfaces. Accordingly I shall not attempt to give for this and subsequent stages the lineage of the individual cells of the ectodermal group. This would be a work of great difficulty and of some uncertainty, for in this case the cells entirely lack those marked differences of size, stainability, and arrangement which make the lineage for the cells of the equatorial band and dorsal hemisphere a matter of perfect definiteness.

If the estimate given of the number of cells in the ectodermal group is correct, the embryo shown in Plate XI. Fig. 71 represents a stage of one hundred and twelve cells distributed as follows.

Ventral hemisphere: —

64 cells in the 9th generation = the ectodermal group,
20 " 8th " } = the equatorial band.
6 " 7th " }
90 —

Dorsal hemisphere :—
2 mesoderm cells in the 7th generation.
10 chorda " 7th "
10 endoderm " 6th "
22 —
90 (in ventral hemisphere).
112

The process of gastrulation has at this stage already set in. Not only is the ectoderm growing over so as to envelop the dorsal hemisphere, but the latter is at the same time sinking down and becoming saucer-shaped. (Cf. Figs. 66 and 77.) Accordingly, gastrulation may be said to take place by a combination of the two processes of epiboly and invagination.

### (*b*) *Differentiation of the Principal Organs as seen at the 112-cell Stage.*

#### α. TOPOGRAPHICAL.

We will now consider this same embryo (Plate XI. Fig. 71) with reference to the ultimate fate of its cells. At the depressed centre of its dorsal surface, surrounding the point of formation of the polar globules, we find the ten cells of the definitive endoderm, all in the sixth generation and containing each a very large nucleus. They are $a^{6.6}$, $a^{6.8}$, $d^{6.5}$, $d^{6.8}$, $d^{6.7}$, and the corresponding cells in quadrants $B$ and $C$. Two of them are derived from each of the anterior quadrants ($A$ and $B$), and three from each of the posterior quadrants ($C$ and $D$). Together they constitute the entire fundament of the definitive larval endoderm.

The endoderm fundament is surrounded by two concentric rows of cells from which are derived some of the most important organs of the larva. The inner row or ring of cells we will call the *chorda-mesenchyme ring,* because it is destined to produce the chorda and mesenchyme. In it we must include the small flattened cells, $C^{7.5}$, $D^{7.5}$, but not their sister cells, $C^{7.6}$, $D^{7.6}$, which, though in contact superficially with endoderm cells, really belong, as their fate shows, in the second or outer ring.

The chorda mother cells, all of which are included in the chorda-mesenchyme ring, are derived, as has been already stated, in part from the anterior and in part from the posterior quadrants. Those derived from the anterior quadrants are at this stage eight in number. They form the anterior segment of the chorda-mesenchyme ring (Fig. 71, $a^{7.9}$, $a^{7.10}$, $a^{7.13}$, $a^{7.14}$, and the corresponding cells on the left of the median plane). The posterior chorda cells are only two in number

($c^{7.11}$, $d^{7.11}$, Fig. 71), one in the right and one in the left half of the embryo. They are now separated both from each other and from the anterior chorda cells. We shall see later how they are brought into contact with each other, in the median plane, and with the anterior chorda cells.

The mesenchyme mother cells are also ten in number, but, unlike the chorda cells, they are derived chiefly from the *posterior* quadrants. They are $A^{8.12}$, its deep-lying sister cell, $A^{8.11}$, $d^{7.12}$, $D^{7.8}$, and $D^{7.5}$, with the corresponding cells in the left half of the embryo, all indicated by a flat tint in the Figures.[1] It will be observed that *the mesenchyme fundament is made up of cells derived from both hemispheres and all four quadrants.*

The outer of the two rows of cells encircling the endoderm fundament will be called the *neuro-muscular ring.* (Fig. 71. The cells are stippled.) It is interrupted at three points by mesenchyme cells of the inner ring; in the middle line behind, by the small flattened cells, $C^{7.5}$, $D^{7.5}$; on the right side, by $A^{8.12}$; and on the left side, by $B^{8.12}$. It is thus divided into three portions, an anterior segment of eight cells, all descended from the anterior quadrants, and two latero-posterior segments, each composed of four cells, descended from one of the posterior quadrants. The anterior segment is composed purely of nerve mother-cells, which will form a considerable portion of the medullary plate. The other segments will form the entire longitudinal musculature of the larva, as well as a certain portion of the nervous system in the tail region.

In the two rings of cells just described are included all save two of the descendants of the cells forming the *equatorial band* of the 48-cell and later stages. These two cells are $D^{8.13}$ and $C^{8.13}$, situated at the posterior margin of the embryo (Fig. 71). They form, in my opinion, definitive ectoderm.

The remaining cells of the embryo number sixty-four, all descendants of the *ectodermal group* of the 48-cell stage. They will form definitive ectoderm, possibly also a portion of the medullary plate.

One again notices in this stage the striking difference in rate of division of the cells which he meets in passing from the vegetative toward the animal pole, a difference which made itself apparent as early as the

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[1] Samassa ('94) identified the mesenchyme mother cells $D^{7.8}$ and $d^{7.12}$ (the cells 8 and 9 of his Fig. 10) as nerve cells. In my preliminary paper I expressed a different opinion, stating that they were mesoderm cells. Subsequent study has confirmed this view, but shown that I was wrong in stating, as I did, that they would contribute to the formation of "the longitudinal musculature of the tail." That organ has, as I shall show, an entirely different and hitherto unsuspected origin.

16-cell stage, and was foreshadowed still earlier by the internal constitution of the unsegmented ovum. The endoderm fundament is in the sixth generation[1] (Plate XI. Fig. 71, $d^{6.7}$, $d^{6.8}$, $d^{6.5}$, $a^{6.8}$, $a^{6.6}$, and the corresponding cells in the left half of the Figure); the chorda-mesenchyme ring is chiefly in the seventh generation, though a single pair of its cells has recently passed into the eighth ($D^{7.5}$, $D^{7.8}$, $d^{7.12}$, $d^{7.11}$, $A^{8.12}$, $A^{8.11}$, — the deep-lying sister cell of $A^{8.12}$, not shown in the Figure, — $a^{7.14}$, $a^{7.13}$, $a^{7.10}$, $a^{7.9}$, and the corresponding cells in quadrants $B$ and $C$); the cells of the neuro-muscular ring are all in the eighth generation, except a single pair which lingers in the seventh ($D^{7.6}$, $D^{8.14}$, $D^{8.7}$, $D^{8.8}$, $A^{8.16}$, $A^{8.15}$, $A^{8.8}$, $A^{8.7}$, and the corresponding cells in quadrants $B$ and $C$); the ectoderm cells are all in the ninth generation, those nearest the animal pole having been the first to divide and pass into that generation. We notice in this stage, as in the earlier stages, a region of delayed division in the equatorial band at the posterior end of the embryo.

### β. Histological.

Figures 63–70 (Plate X.) represent eight cross sections from a series through an embryo (not figured) a little more advanced in development than the one shown in Plate X. Figs. 61 and 62. The approximate position in the embryo of the sections figured is indicated by the horizontal lines on Figure 62.

The differing stainability of cells at this stage, together with other histological peculiarities, serves already to distinguish the fundaments of the various organs with considerable precision.

The endoderm cells ($d^{6.7}$, Fig. 64; $d^{6.8}$, Figs. 65 and 66; $a^{6.8}$, $d^{6.5}$, Fig. 67; $a^{6.6}$, Fig. 68; together with the corresponding cells in the left halves of these Figures) are, on account of their slow division, still very large. They are columnar in form, and contain large nuclei. Their cytoplasmic portion scarcely stains at all except in the region of the nuclei, being almost entirely taken up with close-packed yolk granules. A small amount of protoplasm staining a bright blue in hæmatoxylin extends out from either side of the nucleus in the long axis of the cell. In this small protoplasmic mass evidently lies an attraction sphere close up to the wall of the nucleus. The nuclei themselves contain numerous chromatic granules.

The mesenchyme cells ($D^{7.8}$, Fig. 64; $d^{7.12}$, Figs. 65 and 66; $A^{7.6}$, Fig. 67; together with the corresponding cells in the left halves of these Figures) are sharply distinguished from those of every other tissue by the very intense blue color which they take upon treatment with a hæmatoxylin stain. Their cytoplasm is not homogeneous at this stage, but contains numerous large dark-looking granules. The granules are undoubtedly yolk granules, and their dark appearance can often be seen upon close inspection to be due to an enveloping film of deeply staining protoplasm, which often extends out in radial processes, giving the whole a star-like appearance. This I believe to be caused by the progressive assimilation of the yolk granules and their conversion into protoplasm. In the case of the mitotic cell $A^{7.6}$ (Fig. 67), and likewise of its mate in the left half of the same Figure, the characteristic mesenchyme staining appears only in the more superficial portion of the cell, its deeper portion being loaded with yolk granules, which are still almost unattacked by the protoplasm. Consequently, when the approaching division is accomplished, the sister cells formed will differ from each other in appearance, the more superficial one being deeply stained, the other being stained scarcely at all. Subsequently, however, the yolk-laden cell will come to resemble in appearance its sister cell, and will have the same ultimate fate. The nuclei of the mesenchyme cells resemble closely in appearance those of the endoderm cells. In the case of $c^{7.12}$ and $d^{7.12}$ (Figs. 65 and 66), the nuclei are relatively small on account of recent division.

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[1] See the table on page 275.

The eight *anterior* chorda cells ($a^{7.14}$, Fig. 68; $a^{7.9}$, $a^{7.10}$, and $a^{7.13}$, Fig. 69; together with the corresponding cells in the left halves of these Figures) resemble closely in shape and stainability the endoderm cells. They are smaller, however, and contain nuclei, likewise smaller, with less conspicuous chromatic granules (omitted altogether in the Figures, as previously explained, to aid in readily distinguishing the chorda cells from those of other organs).

The two *posterior* chorda cells ($d^{7.11}$, Fig. 66; $C^{7.11}$ [by mistake of engraver for $c^{7.11}$], Fig. 67) stain more deeply than the anterior chorda cells, resembling to some extent their sister cells $d^{7.12}$ and $c^{7.12}$ (Figs. 65 and 66), from which they have recently been separated by division. However, they are many times smaller than their sister cells, and extend less deeply. This difference is connected with the oblique position of the spindles in the mother cells (see $d^{6.6}$, Fig. 60), a matter to which attention was called in the discussion of the 64-cell stage.

In the neuro-muscular ring the cells (stippled to distinguish them from those of other groups) have about the same histological character in both anterior ($A^{8.16}$, Fig. 68; $A^{8.15}$, Fig. 69; $A^{8.7}$, $A^{8.8}$, Fig. 70; together with the corresponding cells in the left halves of these Figures) and posterior ($D^{8.8}$, Fig. 65; $D^{8.7}$, Fig. 64; $D^{7.6}$, $D^{8.14}$, Fig. 63; together with the corresponding cells in the left halves of these Figures) portions. The cytoplasm is finely granular and pretty homogeneous throughout, except in those portions of the cell most remote from the nucleus, where a certain amount of yolk is to be seen either unassimilated (Fig. 66, $C^{8.8}$) or in process of assimilation (Figs. 68–70, $A^{8.16}$, $A^{8.15}$, $A^{8.8}$, $A^{8.7}$, and their mates in quadrant $B$). In $C^{7.6}$ (the mate of $D^{7.6}$ in Fig. 63) both conditions are realized. Around the nucleus is the finely granular protoplasm, and in those portions of the cell most remote from the nucleus is the unattacked yolk. Forming a sharp line of boundary between the two is a zone in which assimilation is progressing, the yolk granules appearing here as large dark bodies. The color which the cells of the neuro-muscular ring assume is not so deep a blue as that of the mesenchyme cells; it is of a more grayish tint.

## B. Later Stages of Gastrulation.

### (*a*) *From the 112-cell to the 128-cell Stage.*

Figure 72 (Plate XI.) represents a dorsal view of a stage a little more advanced than the 112-cell stage shown in Figure 71. Sections (not figured) of this stage show (cf. sections of an older stage, Figs. 73–77) that the endoderm cells are in mitosis, the spindles being in all cases situated in an approximately horizontal position, so that after division the daughter cells will lie in a single layer forming a curved plate. The spindles are directed longitudinally in all the cells except two, viz. $c^{6.8}$ and $d^{6.8}$ (cf. Plate X. Fig. 62), in which they lie transverse to the long axis of the embryo.

Among the mesenchyme cells division has occurred in $D^{7.8}$, $C^{7.8}$ (cf. Figs. 71 and 74), the spindles standing vertically, as in the case of $A^{7.6}$, $B^{7.6}$ (Plate X. Figs. 62 and 67), which divided earlier. Vertical spindles are also present in $c^{7.12}$, $d^{7.12}$ (cf. Plate XI. Figs. 71 and 75).

The chorda cells are in the same generation as at the last stage, but the anterior ones are laterally compressed into a flattened or wedge shape, their thinner edges being directed backward. They are situated at the anterior margin of the blastopore (Fig. 72).

In the neuro-muscular band, two cells on each side of the blastopore ($D^{8.7}$, $D^{8.8}$, $C^{8.7}$, $C^{8.8}$) are seen to be in mitosis, their spindles being directed toward the centre of the blastopore. No evidence of division can be seen in any other cells of the embryo. It is therefore clear that the considerable advance in the process of gastrulation which is seen to have taken place since the stage shown in Plate XI. Fig. 71, has come about chiefly by an invagination, independent of cell division on the aboral surface, which has carried inward the endoderm and mesenchyme cells, has left at the margin of the wide-open blastopore the anterior chorda cells and the muscle cells, and has brought plainly into view, outside the neuro-muscular band, another row of cells from the ectodermal surface extending round the entire margin of the embryo. A certain number of cells at the anterior end of this new ring is destined to serve the same purpose as the anterior segment of the neuro-muscular band; this fact is indicated in the figure by stippling.

A clearer idea of the changes just sketched in outline may perhaps be had from an examination of cross sections. In Figures 73–77 are represented five sections through the region of the blastopore of an embryo a little more advanced than the one shown in Figure 72. The approximate position of the sections in the embryo is indicated by horizontal lines at the margin of Figure 72. In the endoderm cells the long deferred division leading to the seventh generation has at last been accomplished (Figs. 73–77). The endoderm cells accordingly number twenty, and their nuclei are greatly reduced in size on account of the recent division (cf. $d^{6.8}$, Fig. 66, Plate X., with $d^{7.15}$, $d^{7.16}$, Fig. 75, Plate XI.). The columnar form of the mother cells is retained by their descendants.

It has been already stated that the spindles in the endoderm cells were at the recent division approximately horizontal in position. It is evident, therefore, that before the accomplishment of division the attraction spheres must have shifted from the position which they were seen to occupy in Plate X. Figs. 66–68, for otherwise the spindles would have stood vertically, and a two-layered arrangement of the cells would have resulted, such as we shall see does occur in the case of the mesenchyme cells. No mechanical explanation of this change in the position of the attraction spheres in the endoderm cells offers itself. The longest axis of the cells appears to be continuously the vertical axis, yet the spindles form in a direction transverse to this in every instance. Van Beneden et Julin's ('86) Figures 1 *c* and 2 *c* also show spindles occupying the short axis of the endoderm cells in the case of Clavelina.

Considering now the mesenchyme cells we see (Fig. 74) that $D^{\cdot 8}$, $C^{7.8}$ (Fig. 71) have divided in such a manner that a small superficial cell is separated in each case from a many times larger deep-lying sister cell (cf. Fig. 74, $D^{8.16}$, $D^{8.15}$, $C^{8.16}$, $C^{8.15}$). A division similar in direction and in the inequality of its products is foreshadowed for the next anterior pair of mesenchyme cells (Fig. 75, $c^{7.12}$, $d^{7.12}$), in which the spindles lie much nearer to the superficial than to the deep ends of the cells. The most anterior mesenchyme cells appear in Figure 77 ($A^{8.12}$, $A^{8.11}$, $B^{8.12}$, $B^{8.11}$). They are descended from $A^{7.6}$, $B^{7.6}$ (Plate X. Fig. 62), in which cells the division leading to the eighth generation occurred at a stage considerably earlier than this. (See Plate X. Fig. 67.) In this case also ($A^{7.6}$, $B^{7.6}$) the spindles stood vertically and division was unequal, but the *more superficial* daughter cell was the larger, the deeper one being small and almost entirely filled with unassimilated yolk. (See Plate XI. Fig. 77, $A^{8.12}$, $A^{8.11}$, $B^{8.12}$, $B^{8.11}$.)

The posterior chorda cells ($d^{7.11}$, Fig. 77, and $c^{7.11}$ in the left half of Fig. 76, not lettered) show no essential change since the last stage figured (cf. Plate X. Figs. 66 and 67). The anterior chorda cells do not appear in the sections figured; they are still in the seventh generation.

Division has been completed in $D^{8.7}$, $D^{8.8}$, $C^{8.7}$, $C^{8.8}$ (Fig. 72), four of the neuro-muscular cells lying at the margin of the blastopore. (See Figs. 74–76, $D^{9.13}$, $D^{9.14}$, $D^{9.15}$, $D^{9.16}$, and the corresponding cells in quadrant $C$.) The other cells of the neuro-muscular ring and the entire ectodermal group have not been essentially modified since the last stage figured (Fig. 72).

If the foregoing account is correct, the embryo, sections of which are shown in Figures 73–77, contains one hundred and twenty-eight cells, distributed as follows.

Ventral hemisphere : —
  Ectodermal group :
    64 cells in the 9th generation $\left\{\begin{array}{l}\text{ectoderm.}\\ \text{nerve cells.}\end{array}\right.$
  Equatorial band :
    2 ectoderm cells in the 9th generation.
    8 neuro-muscular cells in the 9th generation.
    10 “ “ “ 8th “
    2 “ “ “ 7th “
    8 mesenchyme “ 8th “
    2 mesenchyme “ 7th “
  32 —
  96

Dorsal hemisphere : —
    2 mesenchyme cells in the 7th generation.
    10 chorda “ “ “
    20 endoderm “ “ “
  32 —
  128

### (*b*) *Closure of the Blastopore.*

In Figure 78 (Plate XI.) is shown a section parallel and slightly lateral to the median plane of an embryo a little more advanced than any thus far examined. It shows how the closure of the blastopore is coming about.

The ectoderm cells on the ventral surface are seen to be smaller toward the anterior (left in the figure) than toward the posterior end of the embryo. They have evidently divided and passed into a later generation than those more posteriorly situated. This has caused them to spread over a greater surface, and has shoved the cells anterior to them farther around on to the dorsal surface of the embryo. In the anterior chorda cells, one of which is seen — in mitosis — in Figure 78 ($a^{8\cdot17}$, $a^{8\cdot18}$), division is nearly completed, the spindles standing about vertically. By the continued overgowth of the anterior lip of the blastopore, the more dorsally situated of the daughter cells in the chorda fundament, e. g. $a^{8\cdot17}$, are carried posterior to their sister cells, e. g. $a^{8\cdot18}$ (cf. Fig. 79), and are finally entirely covered from sight by the nerve cells. They then form a plate of eight cells lying in the dorsal wall of the archenteron anterior to the blastopore.

The endoderm cells of this embryo (Plate XI. Fig. 78) have undergone no new divisions since the 128-cell stage (Figs. 73–77), though their nuclei have considerably increased in size, as is invariably the case during the resting period. More lateral sections than the one shown in Figure 78 exhibit spindles directed longitudinally in the mesenchyme cells $A^{8\cdot12}$, $B^{8\cdot12}$ (cf. Figs. 71 and 77), and show that division has been completed in $d^{7\cdot12}$, $c^{7\cdot12}$ (cf. Fig. 75).

Sections through two other embryos, a little more advanced still in development, show in the muscle cells $C^{7\cdot6}$, $D^{7\cdot6}$ (cf. Figs. 71 and 72) spindles directed forwards, inwards, and downwards, i. e. about toward the centre of the gastral cavity, a condition which is realized in the same cells at a corresponding stage in Clavelina. (See Van Beneden et Julin's ('86) Figs. 1 *a* and 1 *b*.) These facts will aid us in interpreting sections of later stages.

Figure 80 (Plate XI.) exhibits a dorsal view of a stage more advanced than any yet examined. The blastopore has greatly contracted (cf. Fig. 72) and now lies in the posterior half of the embryo. As gastrulation has progressed, there has taken place an ingrowth of cells round the margin of the blastopore into the inner layer of the embryo. We have already seen how by this process the anterior chorda cells attain a position in the dorsal wall of the archenteron; we may now observe that certain cells of the latero-posterior segments of the neuro-muscular ring are also involved in this ingrowth or invagination. At the stage shown in Figures 74–76 there was a double row of neuro-muscular cells on each side of the blastopore, now (see Fig. 80) the inner row is nearly covered from sight by the row of cells outside it.

Already at the stage shown in Figure 72 the most posterior neuromuscular cells ($D^{7.6}$, $C^{7.6}$) had moved from their originally lateral position toward the median plane (cf. Fig. 71). There they were destined presently to meet each other, covering over the small mesenchyme cells $D^{7.5}$, $C^{7.5}$ (cf. Figs. 71 and 72 with Fig. 80); now (Fig. 80) they or their descendants lie at the posterior angle of the blastopore, and are in turn being covered over by the more laterally and anteriorly situated neuromuscular cells.

The nerve cells anterior to the blastopore have increased considerably in number, perhaps through additions from the ectodermal group (cf. Figs. 72 and 80, also Figs. 78 and 79).

Three sections from a horizontal series through an embryo of about the stage shown in Figure 80 are represented in Plate XI. Figs. 81–83. The series consists of thirteen sections 6.67 $\mu$ thick, of which Figure 81 represents the third, Figure 82 the fifth, and Figure 83 the seventh. The sections are a little oblique, and consequently strike the right and left halves of the embryo at slightly different levels. The left side of Figure 82 shows best the history of the mesenchyme cells since the last stage examined in detail (Figs. 73–77). Lateral to the small gastral cavity we find the sister cells $B^{9.23}$, $B^{9.24}$, descendants of the common mother cell $B^{8.12}$ (Fig. 77). Evidence of the derivation of these two cells has been cited in the observation of a spindle longitudinally directed in the cell $B^{8.12}$ in two different embryos less advanced than this.

Lateral to $B^{9.23}$ and $B^{9.24}$ are the sister cells $B^{9.21}$, $B^{9.22}$, descendants of $B^{8.11}$ (Fig. 71; cf. $A^{8.11}$, Fig. 77). They stain more faintly than $B^{9.23}$ and $B^{9.24}$, a distinction which, it will be remembered, existed between the respective mother cells $B^{8.11}$ and $B^{8.12}$ (Fig. 77). Though a spindle has in no embryo been directly observed in $B^{8.11}$, evidence of the sistership of $B^{9.21}$ and $B^{9.22}$ (Fig. 82) exists in the still persistent interzonal filaments which stretch between their nuclei. This evidence is supported by the similarity of the cells in size and stainability. Posterior to the quartette of cells just discussed, the common descendants of $B^{7.6}$ (Plate X. Figs. 62, 67), are the two daughter cells derived from $c^{7.12}$ (Fig. 71), which was seen to be mitotic at an earlier stage (Fig. 75).

It was predicted from the position of the spindle in this cell that the division would be unequal, the more centrally and dorsally situated daughter cell being the smaller. This smaller cell is represented by $c^{8.24}$ (Fig. 82), but only the upper end of its large sister cell, $c^{8.23}$, appears in this section. In Figure 83 (Plate XI.) we see the deeper portion of $c^{8.23}$, which contains a nearly horizontal spindle.

Posterior to the pair of cells just described are the descendants of $C^{7.8}$ (Fig. 71), the next to the hindmost of the mesenchyme cells in the left half of the embryo. In Figure 74 they were in the eighth generation ($C^{8.16}$, $C^{8.15}$). One, the smaller, still remains in that generation ($C^{8.16}$, Fig. 82), but its larger, more deeply situated sister cell has passed into the ninth generation, and is now represented by $C^{9.30}$, $C^{9.29}$, Figure 83. The direct evidence of mitosis has not been observed for the division here assumed, but very strong indirect evidence for it exists in the fact that at the last cell division in the mesenchyme cells, $C^{7.8}$ divided earlier than $c^{7.12}$ (cf. Figs. 74 and 75). If the same order of division is followed in case of the daughter cells, division ought to occur earlier in $C^{8.15}$ than in $c^{8.23}$. But the latter cell is seen in Figure 83 to be in process of division; therefore it is reasonable to suppose that at the same stage the former cell has already divided.

The small posterior mesenchyme cells, $C^{7.5}$, $D^{7.5}$, lie one *behind* the the other deep down in the floor of the gastrula (Fig. 83), just posterior to the endoderm cells and overlaid by muscle cells, — for such the invaginated cells of the neuro-muscular ring become.

These muscle cells have been crowded inward and downward at the posterior margin of the blastopore in consequence of the rapid contraction of that opening.

In the most posterior pair of muscle cells, viz. $C^{7.6}$, $D^{7.6}$ (Fig. 71), mitosis was observed to occur, as already stated, at a stage earlier than this. The daughter cells arising from that division are readily recognized in $C^{8.11}$, $C^{8.12}$, and $D^{8.11}$, $D^{8.12}$ (Fig. 83). The nuclei of $C^{8.11}$ and $D^{8.11}$ lie in the section intermediate between those represented in Figures 82 and 83.

I am not able to declare with certainty the lineage of each of the other muscle cells in this series of sections, so I shall not attempt to point them out one by one. As a group, however, they are clearly distinguished from the ectoderm cells on the one hand, and from the mesenchyme cells on the other, by their large nuclei, their considerable size, and the peculiar stainability of their protoplasm. They resemble very closely in stainability the nerve cells lying anterior to the blastopore, but they are much larger than the nerve cells. They now lie lateral and posterior to the blastopore. (See Figs. 81–83; cf. Figs. 79 and 80.)

The backward growth of the anterior lip of the blastopore has carried the crescent-shaped anterior chorda fundament (Fig. 71) from its original position to about the middle of the embryo's dorsal surface (Fig. 81). It was seen in Figure 71 to consist of eight cells, which have now increased (Figure 78) to sixteen, and lie crowded together in two rows, one superposed above and overhanging the other (cf. Figs. 79 and 81.

In Figures 62 (Plate X.) and 71 (Plate XI.) we saw that the two posterior chorda cells, viz. $c^{7.11}$, $d^{7.11}$, were separated from the anterior chorda cells by the mesenchyme cells, $B^{7.6}$, $A^{7.6}$, or their descendants. In Figure 82 we see that the descendants of $B^{7.6}$, $A^{7.6}$ (viz. $B^{9.21}$, $B^{9.22}$, $B^{9.23}$, $B^{9.24}$, and the corresponding cells in quadrant $A$) during the process of invagination have been pushed down to the level of the other mesenchyme cells, allowing the anterior chorda cells to come into contact with the isolated posterior chorda cells (Fig. 81, $c^{8.21}$, $c^{8.22}$) above them. The posterior chorda cells were seen to be in the seventh generation in Figure 71 ($c^{7.11}$, $d^{7.11}$). At the stage represented in Figure 81, there is good reason to believe that they have divided and passed into the eighth generation, since every other cell of the dorsal hemisphere is known to have done so previous to that stage; they are therefore represented by the cells $c^{8.21}$, $c^{8.22}$, $d^{8.21}$, and $d^{8.22}$, the last named cell being hidden from view in Figure 81 by the overlying muscle cell.

The endoderm cells still remain in the eighth generation, and number twenty. Their arrangement is made clear by an examination of Figures 81–83, in comparison with Figure 79, which represents a section near and parallel to the median plane of a slightly earlier stage. Fourteen of the twenty endoderm cells abut on the median plane, and six are placed laterally toward the anterior end of the embryo. The median double row of cells consists of $b^{7.11}$ (Fig. 81), $b^{7.12}$ (Fig. 82), $b^{7.15}$, $b^{7.16}$, $c^{7.16}$, $c^{7.14}$, $c^{7.13}$ (Fig. 83), and the corresponding cells in the right half of the embryo. The nuclei do not appear in the centrally and posteriorly situated endoderm cells of Figure 83 because they lie in later (deeper) sections of the series, not figured (cf. Fig. 79). Only the narrow upper ends of the cells in question appear in Figure 83, which therefore gives no adequate idea of their size, but a correct idea of this may be had by an examination of Figure 79. The laterally situated endoderm cells are $c^{7.9}$ (Fig. 82), $c^{7.10}$, $c^{7.15}$ (Fig. 83), and the corresponding cells in the right half of the embryo.

From a series of cross sections through an embryo in about the same stage as is represented in Figure 80, four sections have been selected to make more clear the relations of the fundaments of the various organs. (See Plate XII. Figs. 84–87.) Figure 84 represents a section just behind the blastopore (compare with it Plate XI. Fig. 73); in it the ectoderm is seen to have slightly overgrown from behind the most posterior muscle cells. (Compare Fig. 79, Plate XII.) Only one of the pair of small posterior mesenchyme cells ($D^{7.5}$, $C^{7.5}$) appears in the section; the other lies in the section just posterior to this.

Mitosis is again setting in among the endoderm cells, as is shown by the spindle in $d^{7.13}$; the next section anterior to this likewise shows spindles in the endoderm cells that are cut, $c^{7.14}$ and $d^{7.14}$. The spindles in each case (${}^{7.13}$ and ${}^{7.14}$) are directed longitudinally, and in such a manner that the eight resulting cells will all lie in a single slightly concave layer. The consequence of these divisions will be a considerable elongation of the double row of endoderm cells at the posterior end of the embryo.

It is worthy of note, though not shown in this series of sections, that at this division, as in the preceding and in subsequent ones, the spindles of the endoderm cells do not lie in the longest axis of the cells, which is the vertical.

Figure 85 shows a section through the still open blastopore at its posterior margin. A comparison of this figure with Figures 72, 74, and 75 (Plate XI.) shows that the ectoderm has grown rapidly in superficial extent through cell multiplication, and shoved the neuro-muscular cells $C^{9.13}$, $D^{9.13}$, inward to a position overlying their sister cells, $C^{9.14}$, $D^{9.14}$. The small mesenchyme cell, $C^{8.16}$ (cf. Plate XI. Fig. 74, $D^{8.16}$), is in process of division, following the lead of its large sister cell, $C^{8.15}$ (cf. Figs. 74, $D^{8.15}$, and 84, $D^{9.29}$, $D^{9.30}$). The mate of $C^{8.16}$, viz. $D^{8.16}$, has already divided. One of its daughter cells is seen in this section ($D^{9.32}$, Fig. 85), the other lies in the next posterior section. The large mesenchyme cells, $c^{8.23}$, $d^{8.23}$ (Fig. 85), are in mitosis (cf. Plate XI. Fig. 83).

The section represented in Figure 86 encounters the blastopore farther forward than the one last described (Fig. 85), in its broader portion (cf. Plate XI. Figs. 72, 76, and 77). Here, too, the muscle cells have been crowded inward and partially invaginated; $C^{9.15}$ and $D^{9.15}$ overlie their sister cells, $C^{9.16}$ and $D^{9.16}$, respectively. Of the posterior chorda cells only $c^{8.22}$ and $d^{8.22}$ appear in this section. Their more laterally placed sister cells, $c^{8.21}$ and $d^{8.21}$, lie in the next posterior section (not figured), and at a slightly higher level (cf. Fig. 81, Plate XI.).

Figure 87 (Plate XII.) represents the first section anterior to the blastopore (cf. Plate XI. Fig. 80). On its depressed dorsal surface are seen six cells of the anterior chorda fundament, which is being rapidly covered over from the sides and anterior end by the ectoderm. Extending deep down on either side of the chorda appears a deeply stained cell (stippled in the drawing) with large nucleus. These two are the most posterior cells of the medullary plate, which now lies at the dorsal surface of the embryo anterior to the blastopore, having been formed chiefly by the anterior segment of the neuro-muscular ring (cf. Plate XI. Fig. 80).

The mesenchyme cells, $A^{9.24}$, $B^{9.24}$ (Fig. 87), are seen to lie on each side of the gastrula cavity (cf. Plate XI. Fig. 82); lateral to them lie the relatively small and faintly stained mesenchyme cells, $A^{9.22}$, $B^{9.22}$. The respective sister cells of those just mentioned, viz. $A^{9.23}$, $B^{9.23}$, $A^{9.21}$, and $B^{9.21}$ (cf. Plate XI. Fig. 82), lie in the next two posterior sections (not figured).

The stage next to be discussed differs in external appearance from that shown in Figure 80 chiefly, first, in the further contraction of its blastopore to a small aperture in the dorsal surface somewhat posterior to its centre; secondly, in a slight elongation of the embryo and narrowing of its posterior end, foreshadowing the formation of the tail; and thirdly, in a slight depression of the medullary plate to form a neural or medullary groove (cf. Fig. 98).

From a series of transverse sections through an embryo in this stage, five are represented in Plate XII. Figs. 88–92. Figure 88 (Plate XII.) shows a section posterior to the blastopore (cf. Fig. 98). It passes through the region of the small posterior mesenchyme cells, $C^{7.5}$, $D^{7.5}$. Lateral or dorsal to them are seen four pairs of muscle cells containing large nuclei. The finely granular cytoplasm of these muscle cells takes a deep grayish blue stain in hæmatoxylin. Bounding the whole section is the uninterrupted ectoderm.

The next anterior section, which has nearly twice the area of this, is likewise completely surrounded by ectoderm.

The second section anterior to the one shown in Figure 88 is represented in Figure 89 (Plate XII.). Two endoderm cells, the most posterior ones, appear in it. The small size of their nuclei indicates that they belong to a later generation than the endoderm cells seen in Figure 84. Unquestionably they are in the eighth generation. To right and left of them appear two muscle cells, probably descendants of $C^{7.6}$, $D^{7.6}$, Plate XI. Fig. 73 (cf. Plate XI. Fig. 83, $C^{8.11}$, $C^{8.12}$, $D^{8.11}$, and $D^{8.12}$). Lateral to the muscle cells mentioned are seen in Figure 89

(Plate XII.) mesenchyme cells, three on each side. Two of them are undoubtedly descendants of the mesenchyme cells $C^{8.15}$, $D^{8.15}$, shown in Plate XI. Figs. 73 and 74, and represented in Plate XI. Fig. 83, and Plate XII. Fig. 84, by the cells $C^{9.29}$, $C^{9.30}$, $D^{9.29}$, and $D^{9.30}$. Their nuclear condition shows that they have arisen from a recent division. Dorsal to the groups of cells already mentioned are seen in Figure 89 muscle cells extending up in a solid mass to the dorsal surface of the embryo. In the mid-dorsal surface of the section is a pair of cells, probably nerve cells, between which at an earlier stage lay the open blastopore. The periphery of the section is elsewhere bounded by ectoderm.

Figure 90 (Plate XII.) represents the second section anterior to that shown in Figure 89. It passes through the widest portion of the blastopore. The only other section of the series which passes through the blastopore is the next preceding one, in which the blastoporic opening is extremely narrow, in fact, scarcely more than a slit. Figure 91 shows the first section anterior to the blastopore. In it we see a plate of seven cells (*cd.*) belonging to the anterior chorda fundament and forming the roof of the archenteron (cf. Fig. 81). In Figure 90 we find the posterior chorda cells (*cd.*) lateral to the blastopore (cf. Plate XI. Fig. 81, $c^{8.22}$ and $c^{8.21}$). Ventral to the chorda cells in Figures 90 and 91 are the mesenchyme cells descended from $c^{8.23}$, $c^{8.24}$, $d^{8.23}$, and $d^{8.24}$ (cf. Plate XI. Figs. 82 and 83).

Dorsal to the chorda cells in Figure 91 are four cells unquestionably nervous, the two lateral ones being large and in mitosis, the other two small, evidently produced by recent divisions. In the next anterior section (not figured) the two lateral mitotic nerve cells again appear; completely filling the space between them are four small nerve cells similar to the two seen in Figure 91. A medullary groove is thus clearly formed anterior to the blastopore, and the four cells dorsal to the chorda fundament in Figure 91 evidently are only lateral backward prolongations of the medullary plate. The two large cells at the margins of the blastopore in Figure 90 are probably $C^{9.15}$ and $D^{9.15}$ (cf. Fig. 86); their deeper lying sister cells $C^{9.16}$ and $D^{9.16}$ have been carried into the more posterior sections by the crowding backward of the chorda cells and the elongation of the embryo.

Figure 92 (Plate XII.) represents the third section anterior to the one shown in Figure 91. The medullary plate and chorda are here represented each by four cells. The mesenchyme cells visible on each side of the archenteron are $A^{9.23}$, $B^{9.23}$, $A^{9.21}$, and $B^{9.21}$ (cf. Plate XI. Fig. 82). The cells $A^{9.24}$, $B^{9.24}$, $A^{9.22}$, and $B^{9.22}$ (cf. Fig. 82) lie in the next two anterior sections. Of the eight cells mentioned, $A^{9.23}$, $A^{9.24}$, $B^{9.23}$, and $B^{9.24}$ (cf. Fig. 82) are all in mitosis, but the four more laterally situated and smaller ones are still quiescent.

Considering as a whole the mesenchyme of this embryo, we see that it consists of two lateral bands which have elongated with the elongation of the embryo. They now extend through ten different sections from near the anterior end of the embryo to a region posterior to the blastopore (Fig. 89). The muscle cells, on the other hand, are gathered into a pretty compact mass at the sides of and posterior to the blastopore (Figs. 88–90).

In the subsequent stages of development the portion of the embryo lateral and posterior to the blastopore will be rapidly drawn out to form the tail of the larva, while the portion anterior to the blastopore will form the trunk. This will not come about, however, without a considerable shifting of cells from one portion into the other, for the chorda cells, which now lie anterior or lateral to the blastopore, must in large part pass into the tail, while the mesenchyme cells, which are more ventrally located, and some of which now extend behind the blastopore, will all pass forward into the trunk region.

An examination of Figure 98 (Plate XII.) may help to give a clearer idea of the stage just described. This figure shows a section made nearly parallel to the sagittal plane, but a little to one side of it, through an embryo slightly older than the one last under discussion (Figs. 88–92). The anterior chorda fundament, it is seen, has been carried back beyond the middle of the embryo's dorsal surface. The muscle cells have been forced backward and downward into a nearly vertical position behind the blastopore, and are nearly covered over with ectoderm (cf. Fig. 93).

Numerous cell divisions have recently occurred in the ectoderm, and the number of endoderm cells has also plainly increased. A very marked elongation of the embryo has attended these divisions. Several cells in the medullary plate are also dividing. On account of the slight obliquity of the plane of sectioning, the small posterior cells $C^{7.5}$, $D^{7.5}$ (*ms'chy.*), do not actually appear in this section as represented, but have been projected there from the adjacent section. In that section the endoderm extends back in a double row of cells into contact with $C^{7.5}$, $D^{7.5}$, as at the stages shown in Plate XI. Figs. 78 and 79.

In Figures 93–97 (Plate XII.) are represented five cross sections through an embryo in about the same stage as is shown in Figure 98. The approximate position of the sections in the embryo is indicated on

Figure 98 by the five vertical lines 93–97. Figure 93 shows a section posterior to the blastopore. It passes through one (*ms'chy.*) of the small posterior mesenchyme cells, $D^{7.5}$, $C^{7.5}$ (cf. Fig. 88), the other lying in the next section posterior to this. The interior of the section is filled with a solid mass of muscle cells, or more properly nerve cells and muscle cells; for it is highly probable that the four most dorsally situated of these cells, which form a group not quite covered in by the ectoderm, are to become part of the nerve cord of the tail (cf. Plate XIII. Figs. 99–101, *n.*). However, they are not distinguishable in histological characters from the more laterally and ventrally situated cells of the section. Cell division has recently occurred in the ectoderm, which plainly is soon to cover in completely the nerve cells in this region of the embryo. The muscle cells have evidently been reduced in size by division since the stage shown in Figures 88 and 89.

The second section anterior to this is shown in Figure 94. It is the only section of the series which passes through the blastopore, now reduced almost to a slit.

The blastopore is bordered on each side dorsally by a large nerve (?) cell, *n.* (cf. Fig. 90). Ventral to the nerve cells lie the posterior chorda cells, *cd.*, lateral and still ventral to which are muscle cells. The most posterior pair of endoderm cells lies underneath the open blastopore, and a single small mesenchyme cell lies deep down in each half of the section.

The second section anterior to the blastopore is shown in Figure 95; the second section anterior to that, in Figure 96; and one situated still two sections farther forward, in Figure 97.

In Figure 96 the medullary plate is not at all depressed at its centre; it consists of four large cells closely packed together and columnar in form. In Figure 97 the medullary plate is not even flattened, but conforms to the evenly rounded contour of the embryo in that region. It consists of six cells sharply distinguished from the cells of the ectoderm in stainability, though the size of the more lateral ones is not materially different from that of the ectoderm cells. The chorda plate has diminished to a breadth of only three cells in Figure 96, and is entirely wanting in Figure 97, where endoderm cells occupy the space dorsal to the archenteron underneath the medullary plate. The mesenchyme bands cover considerable area in Figure 96, but are reduced to a single cell on each side of the body in Figure 97, from which it is seen that in this region the interior is nearly filled with a solid mass of endoderm. The section represented by Figure 97 lies well toward the anterior end of the embryo, as is indicated by the rapidly diminishing size of the sections.

To summarize our observations on the series of sections just examined (Figs. 93–97): —

(1) The fundament of the *nervous system* consists of a medullary plate extending from near the anterior end of the embryo to the blastopore, and continued backward by cells lying on each side of the blastopore and along the line where the lips of the blastopore have fused. The transformation of the medullary plate into a medullary groove proceeds from the blastopore forward.

(2) The *chorda* fundament consists of a plate of cells immediately underneath the medullary plate, but extending neither so far forward nor so far backward in the embryo. A part of it lies on each side of the blastopore, but the larger part is anterior to the blastopore.

(3) The *mesenchyme* extends in two lateral bands from the region of the blastopore forward through about two thirds of the extent of the embryo anterior to the blastopore.

(4) The *muscle cells* lie principally posterior to the blastopore in a pretty compact mass. They extend no farther forward than the first section anterior to the blastopore.

(5) The *endoderm* consists of a double row of large cells ventrally situated extending from the first section behind the blastopore through the next five anterior sections; it then broadens out and occupies nearly the whole inner layer of the embryo, both dorsally and ventrally, anterior to the chorda fundament.

## C. SUMMARY ON GASTRULATION.

1. In the gastrulation of Ciona two processes can be distinguished: (*a*) a progressive invagination of the cells on the dorsal surface of the embryo, beginning at its centre; (*b*) a concomitant overgrowth of cells from the ventral side of the embryo, caused by more rapid cell division in that region. The overgrowth is greater at the anterior than at the posterior end of the embryo, because cell division proceeds more rapidly at the anterior end.

2. Early in the process of gastrulation one can recognize a ring of cells encircling the blastopore peculiar in their stainability, forming the common fundament of the nervous system and the longitudinal musculature of the larva.[1] Anterior to the blastopore the ring broadens out

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[1] The existence of this peculiar ring of cells was first pointed out by Van Beneden et Julin ('86) in the case of Clavelina; but these authors made the mistake of regarding it as exclusively nervous.

to form the medullary plate. Those cells of this *neuro-muscular* ring which lie on each side of and posterior to the blastopore are for the most part invaginated, and form the entire longitudinal musculature of the tail. Some of them, however, form the most posterior portion of the nerve cord.

3. Lying just within the margin of the blastopore, and encircled by the neuro-muscular ring, is another ring of cells, interrupted at the posterior end of the embryo only. Its anterior portion gives rise to the greater part of the chorda; its remaining (lateral) portions produce the mesenchyme or trunk mesoderm, besides contributing to the chorda a single cell at each lateral margin of the blastopore. The descendants of these two chorda cells meet in the median plane at the closure of the blastopore. They form the most posterior portion of the chorda.

We may regard the chorda-mesenchyme ring as being completed morphologically by the two small sub-chordal mesoderm cells $C^{7.5}$, $D^{7.5}$, which have been wedged in between the most posterior cells of the neuro-muscular ring. Like the other cells of the chorda-mesenchyme ring, they lie in contact with the endoderm cells on one side, and with cells of the neuro-muscular ring on the other. Ultimately they probably form mesenchyme in the tail region. Possibly by a cœnogenetic reduction in size to their present minute dimensions, a gap has been left on each side of the embryo between them and the lateral portions of the chorda-mesenchyme ring. This change may have attended a cœnogenetic lengthening of the posterior end of the organism to subserve locomotion. There is evidence from other sources that the trunk of Ascidians formerly extended farther back into what is now the tail region of the larva. At that time the mesenchyme also probably extended farther back, and the chorda-mesenchyme fundament was in ontogeny, as we suppose it to have been in phylogeny, an uninterrupted ring.

4. The blastopore, at first widely open, closes more rapidly from the anterior margin and from the sides than from behind. Consequently it comes to lie in the posterior portion of the dorsal surface of the embryo, and is triangular in form. The right and left sides of the triangular blastopore, however, fuse from behind forward, beginning in the region of the pair of small, flattened mesoderm cells, $C^{7.5}$, $D^{7.5}$. Along the line of union of the lateral lips of the blastopore lies superficially on each side of the median plane a row of nerve cells. These are subsequently covered in by ectoderm from the sides and from behind, and form the posterior portion of the nerve cord. Underneath them, and at first not distinguishable from them in histological characters, are other cells, likewise derived from

the posterior portion of the neuro-muscular ring; these are destined to form the longitudinal musculature of the tail. The medullary plate, which produces the entire nervous system of the *trunk* region, lies wholly anterior to the region of "concrescence" of the lips of the blastopore.

5. The posterior margin of the blastopore does not grow forward over the blastopore covering in the medullary canal as described by Van Beneden et Julin ('86) in the case of Clavelina.[1]

6. I heartily concur in Samassa's ('94) conclusion that there is no rotation of axes during the gastrulation of Ciona, such as Korschelt u. Heider ('93), on theoretical grounds, conjectured might occur in Ascidians. Their hypothesis is, so far as I know, entirely unsupported by observation.

## 4. Formation of the Larva.

The further changes which the embryo undergoes in its transformation into the larval tadpole will be understood from an examination of Figures 99–105 (Plate XIII.), which represent seven sections through an embryo with completely closed blastopore. Figure 99 shows the third section (in passing from behind forward) of the series; it contains about half a dozen muscle cells and four nerve cells, surrounded by an epithelial layer of ectoderm. The first section of the series shows merely the ectoderm cut tangentially; the second contains six muscle cells surrounded by the ectoderm, but no nerve cells or chorda. The four nerve cells in Figure 99 show precisely the same arrangement as is found later in a cross section of the tail of the larva. (See the four cells at the right of *cd.* in the right portion of Fig. 106.)

In Figure 100 (Plate XIII.) the number of nerve cells (seven) is seen to be increased, and the chorda makes its appearance as a group of seven cells ventral to the nerve cells.

In Figure 101 (Plate XIII.) the nervous and chorda fundaments appear about as in the section shown in Figure 100, but underneath the chorda is seen a group of four small mesoderm cells, the descendants of $D^{7.5}$, $C^{7.5}$ (Plate XII. Fig. 88), which have at last divided. Just anterior to them in the embryo (Figs. 102 and 103) extends the double row of caudal endoderm cells. As I have already suggested (page 262), the subchordal mesoderm cells (Fig. 101) probably have the same fate as the caudal endoderm cells, i. e. are resolved into mesenchyme at a later stage.

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[1] The authors mentioned were doubtless led into this mistaken interpretation by identifying as nerve cells the *muscle* cells which lie behind the blastopore at the time of its closure. (See their Figs. 1 *a*, 1 *c*, 2 *c*, 3 *a*, Pl. VII. These figures are reproduced in Korschelt u. Heider's ('93) Figs. 741 A, 741 B, 742 B, and 745 B, respectively.)

Figure 102 (Plate XIII.) represents a section through what probably was the region of the blastopore. In it is seen the most posterior pair of endoderm cells (cf. Plate XII. Fig. 94). Since the stage last examined (Plate XII. Figs. 93–97) the chorda cells have closed together into a single plate in this region, and the chorda fundament has grown farther back in the embryo. The nerve cells which lay at each side of the blastopore (Plate XII. Fig. 94) have also met in the median plane to form a single plate, which is now closing into a canal. A real canal is never formed posterior to the blastopore, though the nerve cells in that region potentially form one.

Figure 103 (Plate XIII.) represents the second section anterior to the one shown in Figure 102; Figure 104, the second anterior to that; and Figure 105, the fourth anterior to that. It will be seen that the muscle cells which in the series last examined (Figs. 93–97) were aggregated chiefly behind the blastopore, have now extended themselves not only posterior, but also anterior, to the blastopore. They extend as far forward as the next section in front of the one represented by Figure 103, i. e. through three sections anterior to the blastopore. They have pushed before them the mesenchyme, which in this series first appears in the section shown in Figure 103. The chorda fundament has meanwhile moved toward the posterior end of the embryo. It now extends two sections behind the blastopore and overlies the small posterior mesenchyme cells (Fig. 101, cf. Plate XII. Fig. 93). Accompanying the changes just mentioned, has come a diminution of the diameter of the embryo at its posterior end, which is already elongating to form the tail region.

The mesenchyme extends forward of the section shown in Figure 103 through six sections. The medullary plate extends forward two or three sections farther still. The endoderm consists of a double row of cells extending forward underneath the chorda as far as the section seen in Figure 104, in which four endoderm cells are found; the arrangement there shown has been derived from that shown in Plate XII. Fig. 96, and still earlier in Plate XII. Fig. 91, by the meeting in the median plane underneath the chorda of the more laterally placed endoderm cells. Later, these four cells, or their descendants, will move apart so as to enclose between them the lumen of the posterior portion of the digestive tract. Anterior to the section shown in Figure 104 the endoderm rapidly increases in amount, while the chorda and mesenchyme diminish.

In the region shown in Figure 105, it fills the entire interior of the section.

In Figure 106 (Plate XIII.) is shown a section through an embryo in which the tail is already recognizable as a distinct portion of the embryo, though it has not yet reached anything like its maximum length. It is curved ventrad under the trunk, so that the section passes transversely through both trunk and tail. The section passes through the trunk in the brain region, but intersects only one of the mesenchyme bands, the other one not extending so far forward in the embryo. The endoderm cells are seen to have arranged themselves round a potential lumen in the form of an epithelium. However, they still lie two deep in places. Their shape is clearly becoming columnar.

In the tail region appears the chorda, now transformed into a single row of flattened, disk-shaped cells, rapidly becoming vacuolated. They form an axial rod extending through the entire tail region and the posterior portion of the trunk. Dorsal (right in the Figure) to the chorda lies the nerve cord of the tail, composed in cross section of about four small cells.

Ventral to the chorda is the sub-chordal endoderm strand consisting of a double row of cells (*en'drm.*). On each side of the chorda are seen in the section about three muscle cells.

### Summary on Formation of the Larva.

1. The nerve cord in the limited region of concrescence of the lips of the blastopore is covered over by the ectoderm first at its posterior end and then successively in its more anterior regions, following the course of concrescence. The nerve cells in that portion of the embryo never form a *real* canal, but only a *potential* one. They are arranged in a solid strand, which usually shows in cross section four cells placed round a common centre, the potential canal.

The medullary plate arises wholly anterior to the blastopore. At the time when the blastopore is about to close, the medullary plate has come to extend over a great part of the length of the embryo, and has sunk down in the form of a shallow grove deepest at its posterior end, the anterior margin of the blastopore. When the blastopore closes, it begins to form a canal. This process, like the fusion of the lateral margins of the blastopore, advances from behind forward.

2. Beginning shortly before the closure of the blastopore, a rapid elongation of the embryo takes place, accompanied by a considerable change in its form and a rearrangement of the cells composing some of

its organs. The posterior end of the embryo, which toward the completion of gastrulation was broader than the anterior end, becomes narrower and narrower, and ultimately forms the tail, which is curved ventrad around the trunk of the embryo within the egg membranes.

Before the closure of the blastopore the chorda is a plate of cells lying in the dorsal wall of the archenteron, anterior and lateral to the blastopore. The portions lateral to the blastopore meet in the median plane when the blastopore closes. The chorda fundament then elongates, owing to a shoving together of its cells from each side, "like a pack of cards in shuffling" (Van Beneden et Julin), until they form, instead of a plate, a single median row of disk-shaped cells arranged one behind another like a row of coins and reaching backward underneath the nerve cord to the extreme posterior end of the embryo. Anteriorly it terminates not far from the middle of the trunk region.

The muscle cells, which originally lay on each side of and behind the blastopore, extend themselves a single cell deep in two bands, one on each side of the chorda throughout its entire length.

The mesenchyme cells originally formed the lateral portions of the chorda-mesenchyme ring. As the blastopore gradually closed, they were thrust down to a deeper level than the muscle cells, and forward. Ultimately they come to lie wholly in the trunk region, chiefly in its posterior portion, in two pretty compact lateral masses of small deeply stained cells, two or more layers deep. At a still later period, these lateral masses are resolved into migratory cells, i. e. blood corpuscles, mantle cells, etc.

Before the closure of the blastopore the endoderm forms the entire lining of the archenteron in its most anterior portion, where its lumen is almost obliterated. Farther back the chorda forms the dorsal wall of the archenteron, the mesenchyme cells forming its sides, the floor only being occupied by the endoderm cells. In the region where the blastopore closes, the endoderm cells occur only as a double row ventrally situated along the median line.

This double row is extended back in the larva underneath the chorda throughout almost the entire length of the tail, forming a "subchordal endoderm strand," which is ultimately resolved into wandering cells, or perhaps utilized as food material by the mesenchyme cells of the trunk region. At the posterior end of this caudal endoderm strand lie the small mesoderm cells which Van Beneden et Julin mistakenly included in the nervous fundament. These cells are to be regarded as the most posterior constituents of the original chorda-mesenchyme ring.

Like the cells of the endoderm strand just anterior to them, they probably become wandering cells.

In the posterior portion of the trunk region, where before the closure of the blastopore the endoderm strand broadens out into a plate of four or more cells, the more laterally placed endoderm cells move dorsad at the closure of the blastopore, and meet in the median plane underneath the chorda. In this way the endoderm of the trunk region is converted into a closed vesicle, pear-shaped and broadest in its anterior portions; at its posterior end it is overlaid by the chorda and flanked on each side by the mesenchyme.

## VII. DISCUSSION OF SOME THEORETICAL QUESTIONS.

The facts presented in the foregoing pages have a certain bearing on several questions of general interest. Of these I shall make brief reference to, — 1. The origin of the germ layers of Chordates; 2. The Cœlom theory; and 3. The ancestry of Chordates.

### A. Origin of the Germ Layers of Chordates.

According to the generally accepted doctrine of Haeckel, all the higher metazoa are ultimately derived from a simple cup-shaped or sac-like ancestor composed of two cell layers, an inner and an outer, continuous with each other at the margin of the cup or sac. The two cell layers are called the primary germ layers. The outer layer is known as the primary ectoderm; the inner, as the primary endoderm. Among the Chordates, this supposed ancestral condition is most nearly realized in ontogeny in the case of Amphioxus. The homologues of its inner and outer germ layers are traced by embryologists through all the groups of the chordate phylum. A third or middle layer, derived from one or both of the others, makes its appearance between the two primary germ layers in all the higher Metazoa. Whether this middle layer, or mesoderm, is homologous throughout the different groups of Metazoa is one of the most difficult and disputed questions in the whole realm of comparative embryology. Into this question I do not propose to go in this paper; I shall confine my attention to the mesoderm of Chordates.

It is commonly believed that the mesoderm of Chordates is derived entirely from the inner germ layer, which is accordingly often referred to as mes-endoderm. With this view, however, my observations on Ciona force me to take issue. In an earlier part of this paper it has been shown that during the process of gastrulation in Ciona there is a progressive ingrowth of cells around the blastopore from a position in the outer to a position in the inner layer of the gastrula. Whether, therefore, we shall include a particular cell in the primary ectoderm or primary endoderm depends on whether we consider the embryo at an earlier or a later period in the process of gastrulation. Lwoff ('94) has recently stated, and it seems to me on excellent evidence, that in Amphioxus and all Vertebrates there occurs in the formation of the germ layers an ingrowth of cells from the outer to the inner layer of the embryo, very similar to that which I have observed in Ciona. He accordingly distinguishes what we may call a *primary invagination* of the cells destined to form chiefly the alimentary tract from a *secondary invagination* involving the cells destined to form the chorda and a portion of the mesoderm, viz. the musculature. The matter seems to me of sufficient importance to warrant the quotation of the author's own words. Speaking of Amphioxus he says: —

" Ich bin also zum Schluss gekommen, dass *die dorsale Wand der Gastrulahöhle, die ich als dorsale Platte bezeichnen will, von den Ektodermzellen gebildet ist.* Dieses Ergebniss ist von sehr grosser Bedeutung. Wie die weiteren Entwickelungsstadien lehren, stellt diese dorsale Wand die Anlage der Chorda und des Mesoderms dar, indem aus der mittleren Zellenpartie derselben die Chorda, aus zwei seitlichen Theilen das der Chorda anliegende Mesoderm entsteht, aus welchem, wie bekannt, die Muskelelemente entstehen. Dies zeigt, das *die Chorda und das anliegende Mesoderm aus einer ektoblastogenen Anlage entstehen,* die ursprünglich als eine zusammenhängende Platte (dorsale Platte) erscheint. Was die eigentlichen Entodermzellen betrifft, welche die übrige Wandung der Höhle bilden, so will ich hier in Kürze vorbemerken, dass sie jederseits einige an die dorsale Platte angrenzende Zellen als ihren Beitrag zur Bildung des Mesoderms abgeben; die Ränder des übriggebliebenen Entoderms wachsen unter den seitlichen Mesodermanlagen nach der Mittellinie zu, vereinigen sich unter der Chorda und bilden auf solche Weise den Darm.

" *Das Hauptergebniss* dieser Untersuchungen ist, *dass die Einstülpung bei Amphioxus keineswegs als eine einfache Gastrulation zu betrachten ist,* wie es bisher angenommen. *Es sind vielmehr hier zwei verschiedene Processe zu unterscheiden: erstens die Einstülpung der Entodermzellen, aus denen der Darm entsteht; zweitens die Einstülpung der Ektodermzellen vom dorsalen Umschlagsrande aus, welche die ektoblastogene Anlage der Chorda* *und des Mesoderms bildet. Die Einstülpung der Entodermzellen ist als Gastrulation zu betrachten. Es ist ein palingenetischer Process*, den die Chordaten von ihren Vorfahren ererbt zu haben scheinen, wo dieser Process gleichmässig und radial symmetrisch vor sich ging, wie es sich bei einigen wirbellosen Thieren beobachten lässt. *Die Einstülpung der Ektodermzellen ist dagegen als ein coenogenetischer Process zu betrachten, der mit der Bildung des Darmes nichts zu thun hat und durch den die Bildung der ektoblastogenen Anlage der Chorda und des Mesoderms eingeleitet wird.* Wie in den folgenden Abschnitten gezeigt werden soll, lassen sich diese zwei Processe — die Bildung des Darmes und die Bildung der ektoblastogenen Anlage der Chorda und des Mesoderms — auch in der Entwickelung aller Wirbelthiere von einander unterscheiden." (Separate, pp. 11, 12.)

Whether Lwoff is right in including the chorda and the greater portion of the mesoderm of Amphioxus and the Vertebrates in the secondarily invaginated part of the inner germ layer, I do not attempt to say. That question must be decided by an examination of the forms on which he made his observations. However, in Ciona, at least, the cells which are destined to form chorda and mesenchyme (chorda-mesenchyme ring) must be regarded as taking part in a *primary invagination* along with the definitive endoderm. But plainly a very important part of the mesoderm, viz. the cells which form the longitudinal musculature, is carried into the inner layer by a *secondary* invagination. The secondarily invaginated cells are derived from the posterior segments of the neuromuscular ring. At the beginning of gastrulation they clearly lie in the outer layer of the gastrula, but at the conclusion of gastrulation they lie within the margin of the blastopore.

Accordingly, I regard the definitive endoderm fundament and the encircling chorda-mesenchyme ring as constituting the *primary endoderm* in Ciona. In the *primary ectoderm*, I would include the neuro-muscular ring and the "ectodermal group" of cells, both of which lie entirely in the outer layer of the gastrula when the closure of the blastopore begins. If this view is correct, the mesoderm or middle germ layer of Ascidians must be regarded as derived in part from the primary endoderm and in part from the primary ectoderm. Lwoff reached a similar conclusion concerning the origin of the mesoderm in Amphioxus and the Vertebrates. In Ciona that part of the mesoderm which is derived from the outer germ layer produces the longitudinal musculature of the larva. It forms the whole of this tissue, and nothing else. Similarly in Amphioxus and the Vertebrates, Lwoff concluded that the ectodermal mesoderm formed the longitudinal musculature. It would seem, therefore, that the *muscle plate* of the mesodermal somite of Amphioxus is homologous with the muscle cells of the Ciona tadpole. Both in Amphioxus and in Ciona the muscle fundament arises from cells lying lateral to the chorda and derived from the primary ectoderm. In Amphioxus the musculature, like the chorda with which it is intimately associated, becomes (cœnogenetically ?) extended far forward to the anterior end of the trunk region; whereas in Ciona neither musculature nor chorda extends farther forward than about the middle of the trunk region.

The mesoderm lateral to the muscle plates of Amphioxus seems to be the homologue of the mesenchyme of Ciona. Both are derived from the *endodermal* portion of the mesoderm. (Cf. the quotation from Lwoff, pages 268, 269.)

My conclusions differ from those of Lwoff chiefly regarding the origin of the chorda. He considers this organ to be derived from the primary ectoderm in Amphioxus and the Vertebrates, whereas I regard it as formed in Ciona exclusively by the primary endoderm. I think that Lwoff has been led to include the chorda cells in the primary ectoderm chiefly because they are in Amphioxus (as in Ciona) smaller and clearer than the less rapidly cleaving endoderm cells. These criteria I regard as insufficient. Only a study of the cell lineage can give in any case a *positive* answer to the question whether the chorda cells at the beginning of gastrulation lie in the outer or the inner layer of the embryo.

That a distinction is rightly made in the case of Ascidians between the two kinds of mesoderm which I have recognized, viz. musculature and mesenchyme, is unanimously agreed to by embryologists; *but the fact has been heretofore overlooked that these two kinds of mesoderm are derived from different fundaments early distinguishable both histologically and topographically, and that these fundaments should be regarded as derived from different primary germ layers.*

A minor point of theoretical importance is whether or not the chorda shall be regarded as a *mesodermal* organ. Lwoff does not so consider it, though he recognizes two facts which, it seems to me, would naturally lead one to that conclusion: the first, that in Amphioxus and the lower groups of Vertebrates the chorda is derived from a common fundament with what is universally regarded as mesoderm; the second, that the chorda, like the undoubted mesoderm, comes to occupy a position between the inner and outer layers of the embryo. For these two reasons, which I have shown to exist also in the case of Ascidians, we must, to be consistent, regard the chorda as a mesodermal organ.

Seeliger ('85), Davidoff ('89), and Samassa ('94) all state that the first equatorial plane of cleavage in the ascidian egg separates the two primary germ layers. According to my definition of the primary germ layers in Ciona, this is not true, for several of the cells composing the chorda-mesenchyme ring (included by me in the primary endoderm) are derived from the four ventral cells, which according to their view are exclusively ectodermal. The statement that the first equatorial plane of cleavage separates the two primary germ layers is equally untenable, if tested by the definition of primary germ layers accepted by the authors mentioned; for they include in the primary endoderm the *entire mesoderm*, which I have shown to be derived *chiefly* from the four ventral cells, which produce the definitive *ectoderm*.

### B. The Cœlom Theory.

The brothers Hertwig ('81) divided the higher Metazoa into two groups according as the body cavity arises by a pair of outpocketings of the primary endoderm enclosing an *enterocœl* between visceral and parietal mesoderm layers, or by a simple splitting or moving apart of cells in a solid mass of mesoderm, which is then said to enclose a *schizocœl*. The Chordates were unhesitatingly placed by them among the Enterocœlians, and Amphioxus was cited as a typical example. The Tunicates were thus classed as Enterocœlians, though no one had ever observed in their ontogeny the formation of an enterocœl. Van Beneden et Julin ('86) supplied the lack by their studies on Clavelina; but considerable doubt has been thrown on the accuracy of their observations by the independent researches of Seeliger ('85) upon an undetermined species of the same genus, and by those of Davidoff ('91) upon the identical species studied by Van Beneden et Julin. Neither Seeliger nor Davidoff could detect a trace of enterocœl formation in the ontogeny of Clavelina, and Davidoff was equally unsuccessful in finding an enterocœl in Distaplia. My own observations on Ciona are entirely in agreement with those of Seeliger and Davidoff on this point. Van Beneden et Julin, notwithstanding their belief that an enterocœl is formed in Ascidians, as well as in Amphioxus, rejected the classification of the brothers Hertwig on other grounds.

Lwoff ('94) has recently shown that in Amphioxus the cavities enclosed by outpocketings of the wall of the gastral cavity are evanescent structures, and have nothing to do with the subsequently formed body cavity, which, as in all Vertebrates, arises by a wandering apart of mesoderm cells. He therefore concludes "*dass ein wahrer Enterocoelier unter allen Chordaten nicht existirt.*"

I am not able to criticise Lwoff's conclusion from the vantage ground of personal investigation of Amphioxus, but his account bears internal evidence of careful and exact observation. He calls attention to a fact, shown by his figures, that, when the mesodermal pouches arise, spindles, if any are present in the mesoderm cells, invariably stand vertically to the evaginated layer of cells, foreshadowing an arrangement of the daughter cells in two layers. This is exactly the position which the spindles take during gastrulation in the mesenchyme cells of Ciona, but in no other cells of the embryo. The form of division in the mesoderm cells of Amphioxus at the period mentioned tends to obliterate the lumen of the mesodermal pouches, a result which, as Lwoff's figures show, actually comes about. A body cavity is formed only secondarily by the moving apart of the mesoderm cells which are arranged in solid masses, the protovertebræ.

Davidoff ('91) likewise observed in the case of the compound Ascidian, Distaplia, that spindles stand vertically in the cells which give rise to the mesoderm at the time of the separation of the middle germ layer. He believes that the Tunicates can in no sense be regarded as Enterocœlians, and, further, that the distinction made by the brothers Hertwig between those Metazoa which possess a "mesoderm" and those which possess "mesenchyme" is an artificial and unsound one. With these conclusions I entirely agree.

Regarding Rabl's ('89) distinction between "gastral" and "peristomal" mesoderm, my observations lead me to the same conclusion as has been expressed by Davidoff, "dass das *peristomale* Mesoderm der Ascidien sich im weiteren Verlauf der Entwicklung zum *gastralen* herausbildet, oder dass das *gastrale* Mesoderm ursprünglich *peristomales* Mesoderm ist." O. Hertwig ('92) draws a similar conclusion regarding Rabl's distinction as applied to the Vertebrates.

I should also state that both Lwoff and Wilson ('94) find that the pole mesoderm cells described by Hatschek in the case of Amphioxus do not exist. Certainly nothing of the kind is found among Ascidians. Hence we may conclude that such cells are entirely wanting among Chordates.

### C. Ancestry of the Chordates.

To determine the phylogenetic relationship of the Chordates to the other groups of Metazoa is a very difficult problem. Various solutions of it have been offered, but none is very generally accepted among zoölogists. The group is sharply marked off from all others by the possession of certain peculiar characters, such as the chorda, gill slits, and hypophysis. Among the higher Metazoa the Chordates seem to have no *near* relatives.

An ingenious suggestion, which has gained considerable currency, is that a chordate is homologous with an annelid whose dorsal and ventral surfaces are reversed. This "annelid hypothesis" has been ably advocated by Dohrn ('75 and '82–'91) and Eisig ('87). An extensive adverse criticism of the hypothesis has been made by Brooks ('93). Is any light thrown on the question by the ontogenetic history of Tunicates? The evidence from that source seems to me chiefly negative. Recent studies of the embryology of Annelids and Mollusks show a truly marvellous correspondence between the developmental processes in these two groups; it is even possible to refer back particular organs in both to homologous blastomeres, and to trace their differentiation through unmistakably similar processes. No doubt is left in the mind as to the close phylogenetic relationship of Annelids and Mollusks. The embryology of Chordates, however, follows an altogether different course, and is as unlike that of Annelids as the adult forms are different.

It is possible that we must go as far down in the animal scale as the Cœlenterates to find an ancestor *common* to the Chordates and any other group of the higher Metazoa. The embryology of Tunicates seems to me to support this view.

Brooks ('93) has shown good reason for believing that all the principal groups of Metazoa arose as small, permanently pelagic forms, such as we find represented to-day, in a somewhat modified form, by Appendicularia in the case of Chordates.

Amphioxus, because of its adaptation to life on the bottom, has probably undergone considerable modification from the ancestral type. For example, the chorda has been extended forward to the extreme anterior end of the body to admit of the animal's burrowing in the sand; a marked asymmetry of the body has also arisen, and its size has doubtless greatly increased, calling for a metameric arrangement of its organs.

The ascidian tadpole, too, has probably been somewhat modified by a great shortening of the free-swimming (ancestral) period of its existence; but here the changes have probably been restricted to a *suppression* of certain processes or organs, so that those which remain are more certainly ancestral than those which occur even in Amphioxus. The *post-larval* history of Ascidians clearly exhibits a process of degeneration, which of course is wholly cœnogenetic.

## VIII. CONCLUSIONS.

1. In the maturation of the ascidian egg the polar globules arise at the *vegetative* pole, i. e. in the future *endodermal* portion of the egg.

2. The archoplasms (attraction spheres) of the first cleavage spindle, and consequently of all subsequent spindles of the fertilized ascidian egg, are derived exclusively from the spermatazoön.

3. The archoplasm (attraction sphere) is not an organ of heredity, since in sexual reproduction it is frequently derived from one parent only.

4. Cleavage in the ascidian egg is bilateral from the very beginning. The course of cleavage is less variable in the egg of Ciona than in that of Amphioxus or the Vertebrates, and is predetermined by the internal constitution of the unsegmented egg.

5. The first equatorial plane of cleavage does not separate completely the two primary germ layers, though it does separate definitive endoderm from definitive ectoderm.

6. The fundaments of the principal organs are arranged in zones around the chief axis of the egg.

7. The nervous system and the longitudinal musculature of the larva are derived from a *common fundament*, which is a (neuro-muscular) ring of cells encircling the margin of the blastopore. This ring of cells must be regarded as a part of the primary ectoderm.

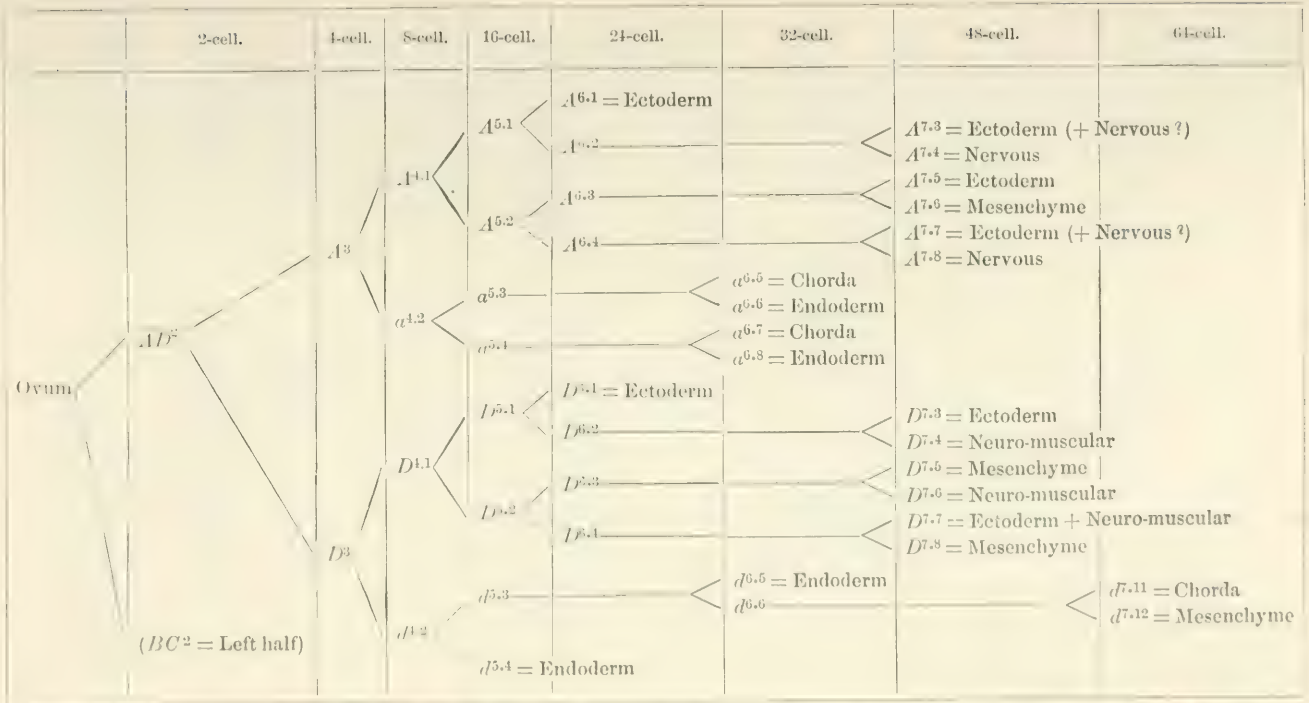
8. The chorda and mesenchyme (or trunk mesoderm) are derived from another ring of cells lying just within the margin of the blastopore. This ring of cells is to be regarded as a part of the primary endoderm.

9. The mesoderm of Ascidians is therefore derived in part from the primary ectoderm, and in part from the primary endoderm. It is formed exclusively by cells of the two rings already mentioned, one of which belongs to each of the two primary germ layers. Recent careful observations indicate that likewise in Amphioxus and the Vertebrates the mesoderm is derived from both primary germ layers.

10. The longitudinal musculature of the Ascidian tadpole is homologous with that of Amphioxus; the mesenchyme of the Ascidian, with the mesoderm lateral to the muscle plates in Amphioxus.

11. The chorda should be regarded as a mesodermal organ.

# IX. TABLE OF CELL LINEAGE OF CIONA.


2-cell.
4-cell.
8-cell.
16-cell.
24-cell.
32-cell.
48-cell.
64-cell.
Ovum
$AD^2$
$(BC^2$ = Left half)
$A^3$
$D^3$
$A^{4.1}$
$a^{4.2}$
$D^{4.1}$
$d^{4.2}$
$A^{5.1}$
$A^{5.2}$
$a^{5.3}$
$a^{5.4}$
$D^{5.1}$
$D^{5.2}$
$d^{5.3}$
$d^{5.4}$ = Endoderm
$A^{6.1}$ = Ectoderm
$A^{6.2}$
$A^{6.3}$
$A^{6.4}$
$D^{6.1}$ = Ectoderm
$D^{6.2}$
$D^{6.3}$
$D^{6.4}$
$a^{6.5}$ = Chorda
$a^{6.6}$ = Endoderm
$a^{6.7}$ = Chorda
$a^{6.8}$ = Endoderm
$d^{6.5}$ = Endoderm
$d^{6.6}$
$A^{7.3}$ = Ectoderm (+ Nervous ?)
$A^{7.4}$ = Nervous
$A^{7.5}$ = Ectoderm
$A^{7.6}$ = Mesenchyme
$A^{7.7}$ = Ectoderm (+ Nervous ?)
$A^{7.8}$ = Nervous
$D^{7.3}$ = Ectoderm
$D^{7.4}$ = Neuro-muscular
$D^{7.5}$ = Mesenchyme
$D^{7.6}$ = Neuro-muscular
$D^{7.7}$ = Ectoderm + Neuro-muscular
$D^{7.8}$ = Mesenchyme
$d^{7.11}$ = Chorda
$d^{7.12}$ = Mesenchyme

*Note.*—In this Table the lineage is given for only the right half of the egg in the 4-cell and subsequent stages. The complete lineage for the *left* half of the egg may be expressed by substituting $B$ for $A$, and $C$ for $D$ in the Table.

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# EXPLANATION OF PLATES.

All Figures were drawn with the aid of the Abbé camera lucida. The magnification is stated for each plate separately. The egg membranes have not been represented in any of the Figures. Arrows in the Figures connect sister cells, i. e. cells which have arisen by division of a common mother cell. For an explanation of the system of nomenclature employed, see page 226.

In many of the Figures, only the cells of one half of the embryo (usually the right, that is, quadrants $A$ and $D$) have been lettered. The reader will be able readily to supply the deficiencies for the cells of the other half, since they are almost perfectly symmetrical in position with those that are lettered. Corresponding to each cell on one side of the median plane (in quadrant $A$ or $D$) will be found a cell similarly situated on the *other* side of the median plane (in quadrant $B$ or $C$); this cell should receive the same exponents as its mate, and either the letter $B$ or $C$ according as that mate is lettered $A$ or $D$. Thus, the mate of $A^{7.2}$ in Figure 58 (Plate X.) is the cell immediately to the right of it, which would be called $B^{7.2}$; the respective mates of $D^{7.5}$ and $D^{7.6}$ in Figure 57 would be called $C^{7.5}$ and $C^{7.6}$.

In Figure 62 (Plate X.) and all following Figures, the endoderm cells are indicated by *granular nuclei* in a cell body that is left without tint or stippling; the chorda cells without tint or stippling, and with the outlines only of nuclei; the mesenchyme cells by a flat tint; the ring of neuro-muscular cells by stippling of the body of the cell. The ectoderm cells, since they are easily distinguishable from the endoderm cells, have been left, like the latter, without stippling or tint; their nuclei are sometimes drawn true to nature, i. e. with granulations, sometimes in outline only.

## ABBREVIATIONS.

*ast.* ♀ = female astral sphere.
*ast.* ♂ = male astral sphere.
*cd.* = chorda.
*cl. pol.* = polar globule.
*cl. pol.*$^{1.}$ = first polar globule.
*ec'drm.* = ectoderm.
*en'drm.* = endoderm.
*ms'chy.* = mesenchyme.
*mu.* = musculature.
*n.* = nervous system.
*pr'nl.* = pronucleus.
*pr'nl.* ♀ = female pronucleus.
*pr'nl.* ♂ = male pronucleus.

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